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BULLETIN
of the
American Association *of* Petroleum Geologists

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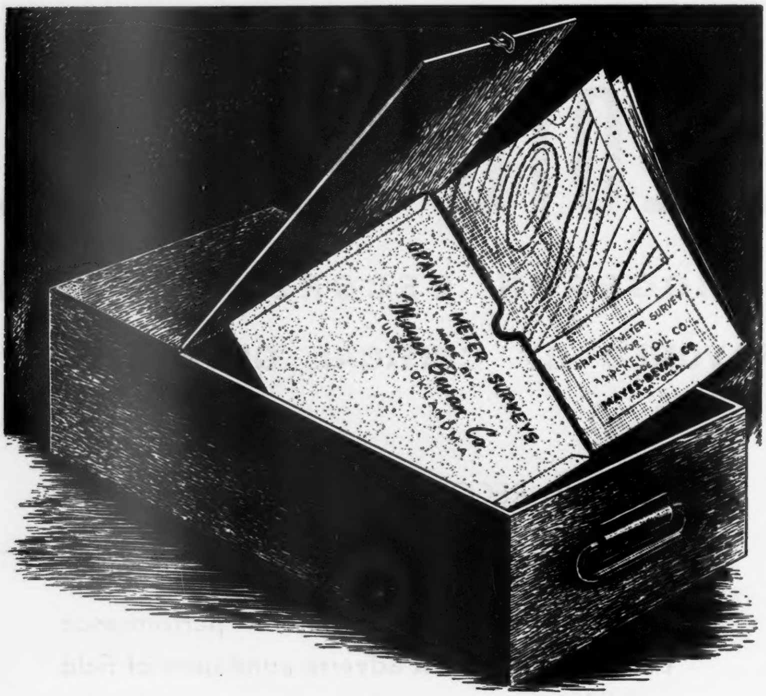
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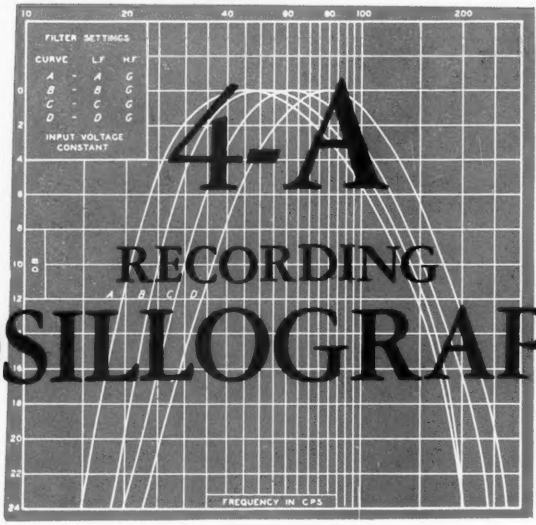

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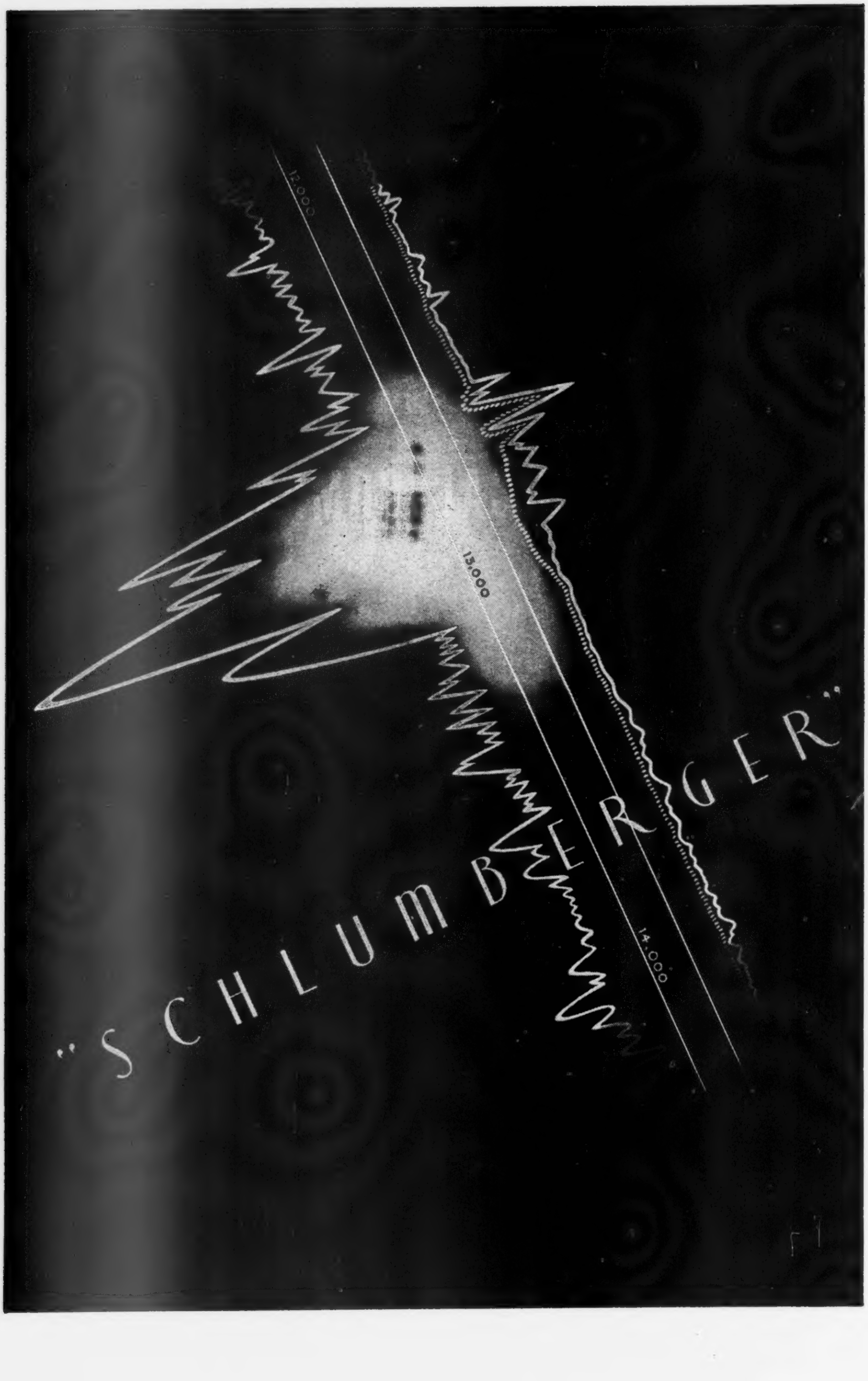
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Volume 29 Number 11

BULLETIN
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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

NOVEMBER, 1945

CLASSIFICATION OF PETROLEUM RESERVOIRS[1]

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Houston, Texas

ABSTRACT

The classification presented in this study divides petroleum reservoirs into five major groups.

A. Convex trap reservoirs
B. Permeability trap reservoirs
C. Pinch-out trap reservoirs
F. Fault trap reservoirs
G. Piercement trap reservoirs

Trapping properties are found in the conditions of reservoir beds, as well as in the configuration of the structural environment in which reservoirs are located. The first set of trapping properties is defined by Trap Indicators and the second set by Environment Indicators. The individual traps which cause the various types of reservoirs result from the logical combinations of these indicators.

The reservoir system is built up inductively and should serve as a tool in the search for petroleum.

I. Introduction

This study is based on the concept that the existence of petroleum reservoirs is due to certain sets of geological factors which cause the trapping of petroleum, and that the great variety in types of reservoirs results from the multiplicity of combinations of such trap-forming factors. It is attempted to establish and define these factors, to describe their function and interrelation, and to derive on this basis a classification that will permit a systematic discussion of petroleum reservoirs.

II. Petroleum Reservoir

DEFINITION

A geological reservoir in its widest sense is a porous stratum that is sufficiently permeable to allow fluids to move through it. In the presence of interconnected

[1] Manuscript received, July 20, 1945.

[2] Production department, Shell Oil Company, Inc.—Texas-Gulf area. The writer wishes to acknowledge the active part taken in the compilation of the reservoir classification by G. Dickinson of the Caribbean Petroleum Company, Maracaibo, Venezuela. Furthermore, the interest shown and the many suggestions made during discussions of the subject with fellow engineers of the production department of Shell Oil Company, Inc.'s Texas-Gulf area are fully appreciated. Finally, the writer is indebted to T. L. Bailey and to G. S. Taitt of the Shell Oil Company, Inc. for reading the manuscript and making suggestions which led to substantial improvement, and to the Shell Oil Company itself for granting permission to publish this paper.

fluid phases of different density and viscosity, such as water and hydrocarbons, the movement of the fluids is influenced by the ever-operative force of gravity, as well as by capillary forces. The fluids, therefore, separate in the order of density, when their flow through a permeable stratum is arrested by intercepting rocks of low permeability, and, in time, a petroleum reservoir is formed in such a "trap." Geologically, a petroleum reservoir is thus defined as a *complex of permeable rock which contains an accumulation of hydrocarbons under a set of geological conditions that prevents escape by gravitational or capillary forces.*

All petroleum reservoirs are covered by rocks of low permeability, and some are completely enclosed in such rocks. As a rule, however, the accumulations of petroleum are underlain by free water. Certain reservoirs are interbedded by relatively impervious layers, such as shale breaks between porous sands or dense streaks between porous zones in limestone. In spite of such conditions, the oil-water interfaces in the various porous members are often at a common level, indicating that permeability in the relatively dense zones was sufficient to allow equalization during geological time. This is, however, by no means a strict rule, and the assumption of a common oil-water interface for productive zones in porous beds alternating with tight layers must be made with reservation, pending the actual observation of the water contact in each productive member of the zone.

With a few exceptions, petroleum reservoirs are located in porous rocks of sedimentary origin, principally in sands and limestones. Some characteristics of the porosity conditions encountered in these formations are reviewed as a preliminary to the classification and general geological discussion of petroleum reservoirs.

SAND RESERVOIRS

Porosity and permeability in the clastic sandy sediments are due to their fragmental texture. The reservoir space depends on (1) grain size, (2) sorting, (3) packing, (4) contamination by fine-grained material, such as clay or silt, deposited in the voids between the sand grains (argillaceous or silty sands), (5) degree of cementation which may range from 0 to 100 per cent with the porosity affected in inverse ratio (calcareous, siliceous, ferrugineous sandstones); fully cemented sandstones may be porous and permeable on account of fracturing (fissured sandstones).

Most blanket sands of wide extent are well stratified, with porosity and permeability oriented by stratification. Lenticular sands deposited on beaches and at off-shore bars are sorted by wave action and porosity and permeability trend parallel with the shore lines. This may be distinct enough to be reflected in the productivity of the wells producing from such sands, for example, the Burbank field, Oklahoma.[3]

[3] N. W. Bass, "Significance of Initial Daily Production of Wells in Burbank and South Burbank Oil Fields, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 6 (1941).

Many sand reservoirs show lateral or vertical gradation of porosity due to shale and silt content or as a result of partial cementation. These variations may only reduce the volume of the reservoir space, or they may be sufficient to cause actual reservoir barriers.

LIMESTONE RESERVOIRS

In the following, the term "limestone" is used for both limestone and dolomite, and the distinction, if necessary, is made by the terms of "calcitic limestone" and "dolomitic limestone."

The limestone deposits connected with petroleum reservoirs are formed in several different ways.

1. Accumulation of skeletal and protective structures of marine organisms living in shallow seas and lagoons
   a. Reefs (bioherms) composed largely of colonies of marine organisms, such as sponges, corals, crinoids, bryozoans, calcareous algae
   b. Coquina and shell breccia, representing aggregates of large foraminifera (orbitoids, fusulinoids, nummulites) or of more or less fragmentary brachiopods, pelecypods, gastropods, or lamellibranchs. These rocks are in places stratified by wave action and may be considered as clastic
2. Segregation due to activity of bacteria in shallow seas
3. Deposition due to inorganic chemical processes in shallow seas; *2* and *3* produce more or less dense, homogeneous limestones, and also porous oölitic limestones
4. Deposition due to physical processes creating clastic limestone sediments (detrital limestone)
5. Base exchange of calcium and magnesium, which appears to be the origin of the marine dolomitic limestones and dolomites. The process is, however, not yet thoroughly understood. Under the predominant view precipitation of calcium-magnesium carbonate is rare and most dolomites are probably formed by replacement in the presence of magnesium-bearing connate water during the period of compaction and lithification of the original lime sediment
6. Chemical change of residual anhydrite concentrated at the top of shallow salt plugs; limestone, free sulphur, and sulphur compounds are formed by reaction with CO_2 introduced with surface water and under bacterial action

By reference to the primary textures formed in the periods of deposition and lithification of these sediments, several forms of *primary porosity* can be recognized.

a. Intercrystalline and intergranular porosity are due to massive crystalline textures formed by interlocking crystals. The finest grades of these textures are of amorphous appearance to the naked eye and the coarser grades are granular. Porosity is not necessarily interconnected and permeability low in general. Even if porosity is macroscopic (pin-point porosity) and shows "bleeding oil," the formation may not be able to produce.

b. Some highly dolomitic limestone approaching pure dolomite has high intergranular porosity and sufficient permeability to form a favorable reservoir rock. It has a sugar-like appearance and its porosity is therefore frequently called "saccharoidal." The formation of this porous rock may be due to the volume shrinkage of 12.3 per cent that attends the chemical changes from limestone to dolomite (dolomitization).

c. Good porosity may be found in the clastic detrital limestones. This type of porosity is more likely to be interconnected than intergranular porosity of

crystalline limestones. However, the grains may be enlarged by secondary deposition of calcite which reduces porosity and the reservoir space considerably.

d. Porosity and permeability in oölitic limestone are favorable for reservoir conditions if the interstices between the oölites are not cemented or only partly filled with cementing material.

e. Porosity and permeability in limestones with skeletal and coquinoid textures are favorable for reservoir conditions if the rocks are uncemented.

A large group of limestone reservoirs owe their favorable porosity and permeability to *secondary solution* from circulating waters in action after lithification of the rock. The solution process was chemical, and organic acids formed under the influence of bacteria have probably played a considerable part. It is known in this connection that ground-water circulates to considerable depth below the water table and studies of caves suggest that even the largest caverns may be of so-called "phreatic origin," that is, formed by solution below the water table. Several "phreatic solution features" believed to indicate the incipient solution patterns of cavern history have been observed:[4]

a. Sponge patterns formed by interconnected solution chambers with relations as complicated as those between the pores of a sponge;
b. "Bedding-plane anastomosis" due to solution by water circulating on bedding planes and attacking the base of the overlying stratum; the solution channels are meandering and in cross sections they show up as rows of subequal holes at the bottom of the stratum;
c. "Joint-plane anastomosis" due to solutional widening of joints and fractures showing intricate designs of shallow half pockets. This solution pattern grades into
d. A network controlled by joint and fracture patterns with narrow solution passages along fracture planes and solution chambers at the intersection of the passages.

Cores from limestone reservoirs display similar types of porosity features, being described as cavernous, spongy, vesicular, honey-combined, *et cetera*, all indicating possible phreatic origin. The highest porosities are found in petroleum reservoirs believed to be associated with limestone reefs. Many cores from such formations show that entire fossil structures were removed by leaching, leaving cavities of corresponding shape. Moreover, the presence of larger caverns in these reservoir rocks is indicated by the dropping of tools during drilling operations.

Disconformities or angular unconformities are in some places connected with zones of secondary solution. It is not fundamentally necessary, however, to associate solution porosity with unconformities. Under the concept that ground water penetrates considerably below the water table, access may be provided by networks of primary porosity, or by fractures, joints and bedding planes, or along

[4] J H. Bretz, "Vadose and Phreatic Features of Limestone Caverns," *Jour. Geol.*, Vol. 50, No. 6 (1942).

permeable sandy layers, as indicated here and there by high porosity in limestone beds adjoining interbedded sands. Locally, highest solution porosity is noted at the crest of some anticlinal structures or along regional flexures, which is probably due to the concentration of fractures and joints along these structural lines. Finally, it should be mentioned that fracturing and fissuring alone can produce a sufficient degree of porosity and permeability to render reservoir conditions favorable. In particular, reservoirs in siliceous limestones of low solubility show this type of porosity.

Thus, porosity and permeability in limestone reservoirs present difficult subsurface problems. In addition to questions on the nature of porosity, it should be emphasized that several types of porosity are commonly involved in the same reservoir and that multiple-type porosity implies multiple-phase production performance.

LIST OF RESERVOIR ROCKS

The following is a list of reservoir rocks arranged to conform with the preceding discussions; the references—common, frequent, infrequent, rare—indicate the relative frequency of occurrence.

1. SAND, CONGLOMERATIC SAND, and GRAVEL, in varying state of consolidation, porosity due to fragmental textures; common
   - a. Clean sands, *et cetera;* pore space between sand grains uncontaminated
   - b. Argillaceous sands, *et cetera;* pore space partly filled with argillaceous matter
   - c. Silty sands, *et cetera;* pore space partly filled with silt
   - d. Lignitic sands, *et cetera;* pore space partly filled with lignitic matter
   - e. Bentonitic sands; pore space partly filled with volcanic ash
2. POROUS CALCAREOUS SANDSTONE AND SILICEOUS SANDSTONE, porosity due to incomplete cementation; frequent
3. FRACTURED SANDSTONE and FRACTURED CONGLOMERATE, porosity due to fracturing in tight sandstones or hard conglomerates caused by faulting or sharp folding; infrequent
4. ARKOSIC (FELDSPATHIC) SAND, ARKOSE, ARKOSIC CONGLOMERATE (GRANITE WASH), porosity due to fragmental texture; infrequent
5. DETRITAL LIMESTONE (calcitic and dolomitic), porosity due to fragmental texture and frequently increased by solution; common
6. POROUS CRYSTALLINE LIMESTONE (calcitic and dolomitic), porosity due mainly to solution; common
7. CAVERNOUS CRYSTALLINE LIMESTONE (calcitic and dolomitic), porosity due to strong solution effects; common. Note: 5, 6, and 7 are not sharply separable
8. FRACTURED LIMESTONE (calcitic, dolomitic, and siliceous), porosity due to open fissures along fracture patterns; frequent
9. SUGARY DOLOMITE, "saccharoidal" porosity possibly due to volume shrinkage in the process of formation of dolomite from calcitic sediment; common
10. OÖLITIC LIMESTONE, porosity due to oölitic texture with uncemented or partially cemented interstices; frequent
11. COQUINA and SHELL BRECCIA, porosity due to fragmental texture; infrequent
12. CRINOIDAL LIMESTONE, a variety of coquina, porosity due to fragmental texture; infrequent
13. POROUS CAP ROCK on shallow salt plugs, porosity due to solution; infrequent
14. HONEY-COMBED ANHYDRITE, porosity due to leaching; rare
15. FRACTURED SHALE, porosity due to fracturing of brittle siliceous shale under sharp folding; rare
16. FRACTURED CHERT, porosity due to fracturing under sharp folding; rare
17. POROUS TECTONIC BRECCIA, formed along fault and thrust zones, porosity mainly due to incomplete cementation or subsequent solution; rare
18. CONTACT-METAMORPHIC SHALES, porosity due to volume shrinkage after "baking"; rare
19. POROUS IGNEOUS ROCK, porosity primary as in tuffs, or due to fracturing as in basalt, or due to decomposition; rare

III. Classification of Petroleum Reservoirs

Petroleum reservoirs are mostly classified with reference to the structural and stratigraphic factors connected with the accumulation. The numerous types of reservoirs are due to the multitude of such factors and their combinations, and the search for a foundation for a systematic division has proved to be a difficult undertaking. In the earlier attempts, structural conditions were principally emphasized as a basis for classification, as in the work of F. G. Clapp.[5] Later, due consideration was also given to the stratigraphic criteria that are in strong evidence in many groups of reservoirs. This led to the widely accepted system worked out by W. B. Wilson[6] and a more recent classification by C. W. Sanders.[7] In principle these authors differentiate structural, stratigraphic, and combination traps, the last including the types where combinations of structural and stratigraphic features are required to complete the traps. A new classification by S. J. Pirson[8] leans on the geologic origin of the traps.

The system here discussed is based on the concept that typical traps are formed by combination of two or more of a group of geological factors which are considered to be the following.

1. Structural environment
2. Convexity in the surface of a reservoir bed which may be due to folding, differential thickness, differential porosity, or to combination of these factors
3. Loss of porosity and permeability in a reservoir bed in lateral direction, including interruption of porosity and permeability by lithologic change, for example, from sand to shale
4. Stratigraphic pinch-out of a reservoir bed
5. Structural interruption of a reservoir bed, either by faulting or by tectonic piercement

Factor 1, indicating the structural environment of a reservoir, is naturally present in every case. It expresses the structural attitude of the strata in the reservoir area, but does not refer to the reservoir bed. Factors 2 to 5, on the other hand, deal with the situation in the reservoir bed. They point out the different conditions that intercept the movement of the fluids and that are thus responsible for the different types of traps. On this basis, two kinds of reservoir indicators have been adopted by means of which a complete geological definition of any reservoir is attempted. The indicators are "Structural Environment Indicators," derived from Factor 1, and "Trap Indicators," derived from Factors 2 to 5, and described as follows.

Structural Environment Indicators (Fig. 1)

I. Dome and anticline, representing the most important types of uplifts in oil-field structures; for classification purposes, additional distinctions are made by:

[5] F. G. Clapp, "Revision of Structural Classification of Petroleum and Natural Gas Fields," *Bull. Geol. Soc. America*, Vol. 28 (1917).
———, "Role of Geologic Structure in the Accumulation of Petroleum," *Structure of Typical American Oil Fields*, Vol. II, Amer. Assoc. Petrol. Geol. (1929).

[6] W. B. Wilson, "Proposed Classification of Oil and Gas Reservoirs," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934).

[7] C. W. Sanders, "Stratigraphic Type Oil Fields and Proposed New Classification of Reservoir Traps," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 4 (1943).

[8] S. J. Pirson, "Genetic and Morphologic Classification of Reservoirs," *Oil Weekly*, Vol. 118, No. 2 (June 18, 1945).

Ia. Indicating the apex or structural center of a dome or the axial culmination of an anticline,
Is. Designating a piercement-type salt dome uplift, where the presence of a salt plug dominates the environment of the reservoir,
Id. Designating a diapiric uplift, where the presence of a diapiric shale core controls the environment of the reservoir,
Ii. Designating a volcanic uplift, where the presence of an igneous plug controls the environment of the reservoir.

II. STRUCTURAL SALIENT: NOSE, ARCH, PROMONTORY
III. STRUCTURAL TERRACE OR PLATFORM
IV. MONOCLINE: HOMOCLINE, FLEXURE
V. PLUNGING SYNCLINE
VI. Absence of controlling structural condition

TRAP INDICATORS (FIG. 2)

A. CONVEX TRAP: A convex surface in an *uninterrupted* porous zone
B. PERMEABILITY TRAP: Lateral disappearance of porosity and permeability in a porous layer
C. PINCH-OUT TRAP: Stratigraphic wedging-out of a porous layer
F. FAULT TRAP: Interruption by faulting of a porous layer
G. PIERCEMENT TRAP: Interruption by tectonic piercement of a porous layer

The logical combinations of the foregoing trap and environment indicators should define and classify the numerous types of reservoirs. A system can be established either with reference to the structural environment indicators or with reference to the trap indicators. The latter choice appears preferable and is followed in the present classification. Accordingly, reservoirs are divided into groups designated by the foregoing trap indicators. Each group can be defined most conveniently by the distinctive characteristics of the reservoir peripheries which result from the various types of traps. The *reservoir groups* and their distinctions are therefore the following.

Group A. CONVEX TRAP RESERVOIRS which are completely surrounded by edge water as the porosity extends in all directions beyond the reservoir areas. The reservoir peripheries are therefore defined by uninterrupted edge-water limits. The trap is due to convexity alone
Group B. PERMEABILITY TRAP RESERVOIRS with the periphery partly defined by edge water and partly by the barrier resulting from loss of permeability in the reservoir layer. In the extreme case a reservoir may be entirely surrounded by such a barrier
Group C. PINCH-OUT TRAP RESERVOIRS with the periphery partly defined by edge water and partly by the margin due to the pinch-out of the reservoir bed
Group F. FAULT TRAP RESERVOIRS with the periphery partly defined by edge water and partly by a fault boundary
Group G. PIERCEMENT TRAP RESERVOIRS with the periphery partly defined by edge water and partly by a piercement contact

By introducing the environment indicator, each group is divided into six *types*, identified by the structural environment and designated by the respective environment indicators, for example, the following.

Type A-I. Convex Trap Reservoir on dome or anticline
Type A-II. Convex Trap Reservoir on structural salient (nose, arch, promontory)
Type A-III. Convex Trap Reservoir on structural terrace or platform
Type A-IV. Convex Trap Reservoir on monocline (homocline or flexure)
Type A-V. Convex Trap Reservoir in syncline
Type A-VI. Convex Trap Reservoir in an environment without any structural influence, that is, in a practically horizontal structural area

To this point, the foundation for a reservoir system takes care only of simple reservoirs that are completely defined by a single trap indicator and an environment indicator. However, single trap reservoirs represent but one group of

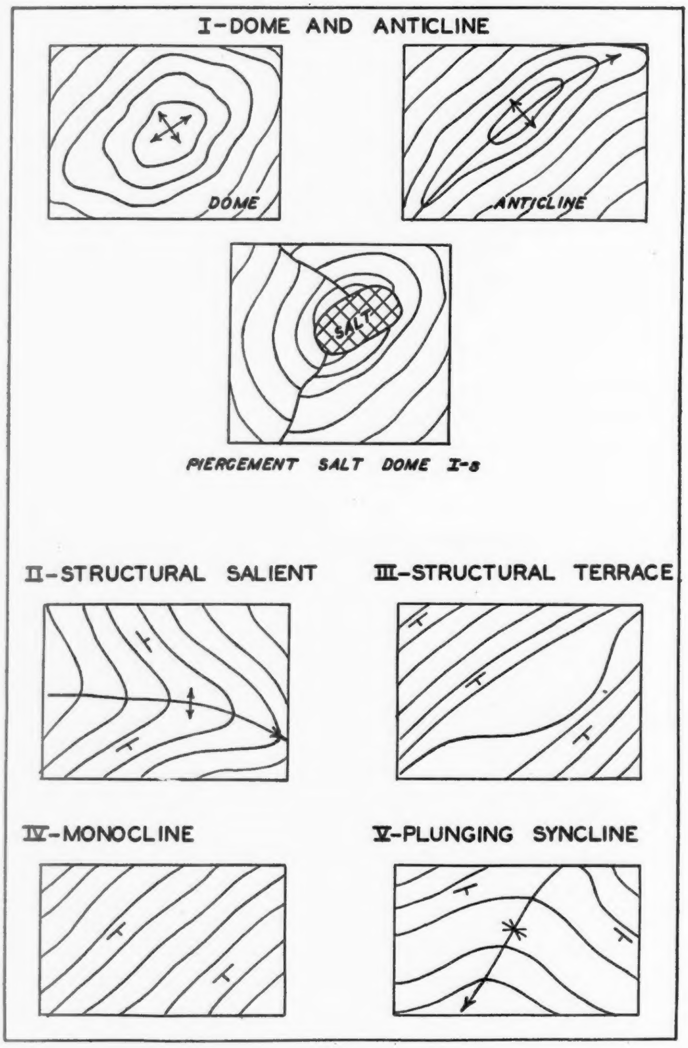


FIG. 1 STRUCTURAL ENVIRONMENTS (CONTOURED)

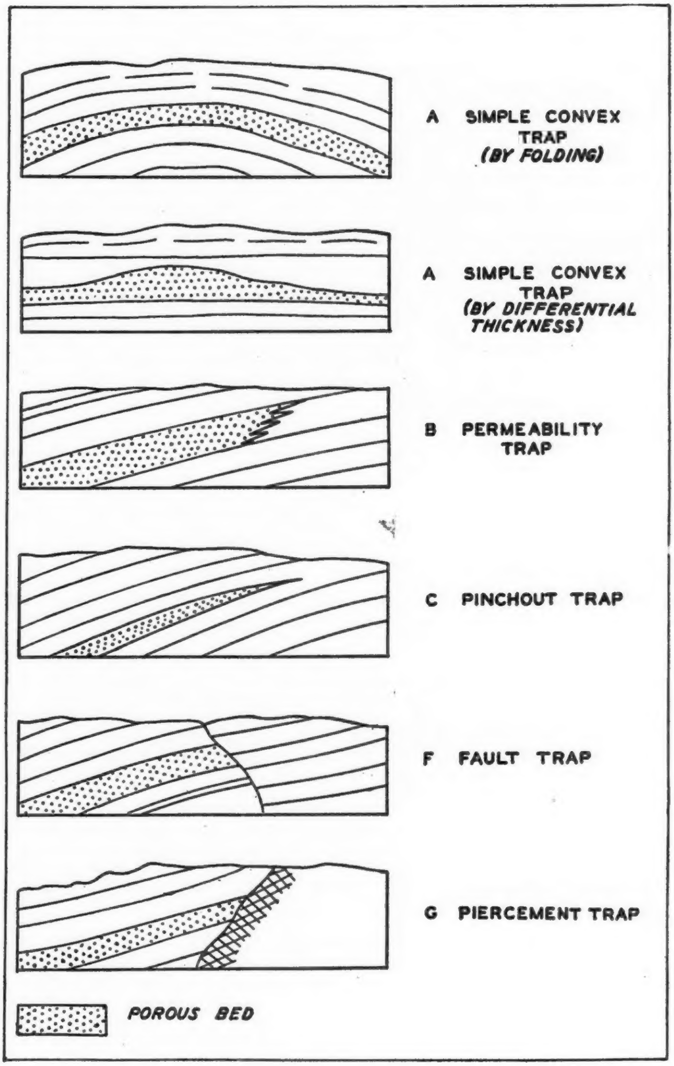


FIG. 2 ELEMENTARY RESERVOIR TRAPS IN SECTION

several *morphological varieties* of reservoirs. In many places, more than one trap indicator is necessary to complete a trap. Moreover, reservoirs can be modified in many ways by trap indicators which interfere accidentally in the reservoir area. Such indicators then play only an incidental part, since they would not eliminate the trap by their absence. Finally, reservoirs may be made up of several units, either connected by permeability or disconnected.

Therefore, a complete description of petroleum reservoirs and their classification requires consideration of all indicators which are involved in the boundaries of the individual reservoirs. To devise a way fitting all varieties conveniently into the system under discussion, the use of reservoir symbols is adopted. These symbols are based on the letters and numerals applied in the foregoing enumeration of the reservoir indicators. The manner in which they are arranged to express the various relationships and thereby the different reservoir varieties, is illustrated by the following examples (Fig. 3).

(1) F-II
A Single Fault Trap Reservoir on a structural nose. The trap is formed by a fault cutting across the axis of the nose. Both indicators are essential for this reservoir and define the reservoir completely as a single trap reservoir

(2) F/B-II
A Modified Fault Trap Reservoir, essentially formed by F and II. But the reservoir is restricted by a barrier due to loss of permeability in the reservoir bed as shown by the permeability trap indicator B. However, this latter indicator is incidental as the trapping conditions are complete with F and II

(3) F×B-II
A Double Trap Reservoir on a structural nose where a couple of trap indicators and the environment indicator are necessary to define the trap. In this case factor B is essential as F and II alone do not complete closure

(4) F×F×B-IV
A Triple Trap Reservoir on a monocline with three trap indicators, all of which are essential as no trap would be formed by one or two of the trap indicators only

(5) B/II
A Lenticular Permeability Trap Reservoir in an isolated permeable lense located on a structural nose. The reservoir is completely surrounded by impervious formation and the environment indicator is incidental; it merely points out the nature of the structural environment in which the reservoir occurs

(6) B-IV/II
A Permeability Trap Reservoir in a monoclinal position on the flank of a structural nose. Within the restricted area of the reservoir the structural position is monoclinal and it would therefore be correct to define this reservoir by the symbol B-IV. However, to give the complete description of the structural environment, the indicator II is added as an incidental indicator

(7) B-II/I
A Permeability Trap Reservoir on the plunging axis of an anticline. Within the reservoir area the structural position is identical with that on a structural nose and the reservoir symbol B-II would be complete. The indicator I is added to give the full description of the environment

(8) A(F)-Ia (Fig. 4)
A Composite Convex Trap Reservoir spread across several blocks of the block-faulted apex of a dome. In this case, a common oil-water interface indicates a single reservoir. Evidently the faulting, however prominent, is not a necessary trap feature

(9) A+B-Ia
A Composite Reservoir located on an anticline and consisting of a Simple Convex Trap Reservoir communicating with a Permeability Trap Reservoir, for example, "Big lime" plus River-bed Sand in the Yates field in West Texas, schematically shown in Figure 4

(10) m(A)-Ia
A Complex Convex Trap Reservoir, representing a productive interval which is composed of individual Simple Convex Trap Reservoir units, each with an individual edge water.

This reservoir occurs in formations consisting of rapidly alternating beds of porous and tight layers, such as sand and shale. However, the reservoir is regarded as a type from geological viewpoints only, since the separate units show individual production behavior, even to the extent that some productive units may have water drive and others depletion-type characteristics. Examples of Complex Convex Trap Reservoirs extending over great vertical intervals are found, for instance, in the Los Angeles Basin in California.[9]

(11) m(B)-Ia

A Complex Permeability Trap Reservoir composed of separate accumulations in lenticular porous members with separate oil-water contacts for each member; some of the porous lenses may be entirely saturated and may contain no water. The separate units are Premeability Trap Reservoirs. Also, in this case the reservoir as a whole can be considered as an individual type from geological viewpoints only, for example, Morgan sands in Schuler field, Arkansas.[10]

In summary, the principal morphological varieties of reservoirs as derived from relationships between the reservoir indicators are the following.

Reservoir	*Example*
Single Trap	F-II
Double Trap	F×B-II
Triple Trap	F×F×B-IV
Modified	F/B-II
Lenticular	B/II
Composite	A(F)-Ia
Complex	m(A)-Ia

The preceding foundation attempts to take into account all trap-forming factors participating in the boundaries of petroleum reservoirs. This permits conducting a systematic examination by logical combination of the established reservoir indicators and thus considering each type of trap condition under each form of structural relation in the entire range from the dome to the syncline. Many reservoirs are indicated in this manner which are rarely, if ever, recognized as typical, and since the system should disclose all types of traps that exist under given structural and stratigraphic conditions, it should serve as an instrument for inductive approach in the search for untapped petroleum reservoirs in productive areas as well as in exploratory territory.

IV. Systematic Geological Discussion of Petroleum Reservoirs

A. convex trap reservoirs

By the foregoing definition of the reservoir groups the Convex Trap Reservoirs are characterized by an uninterrupted edge water surrounding the reservoir entirely, because the porosity is unrestricted and extends in all directions beyond the reservoir area. The description of the morphological varieties of reservoirs indicated that certain composite and complex reservoirs belong in the group of Convex Trap Reservoirs, which are therefore divided into

Simple Convex Trap Reservoirs
Composite Convex Trap Reservoirs
Complex Convex Trap Reservoirs

[9] *California Div. Mines Bull. 118* (1943).

[10] W. B. Weeks and C. W. Alexander, "Schuler Field, Union County, Arkansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 9 (1942).

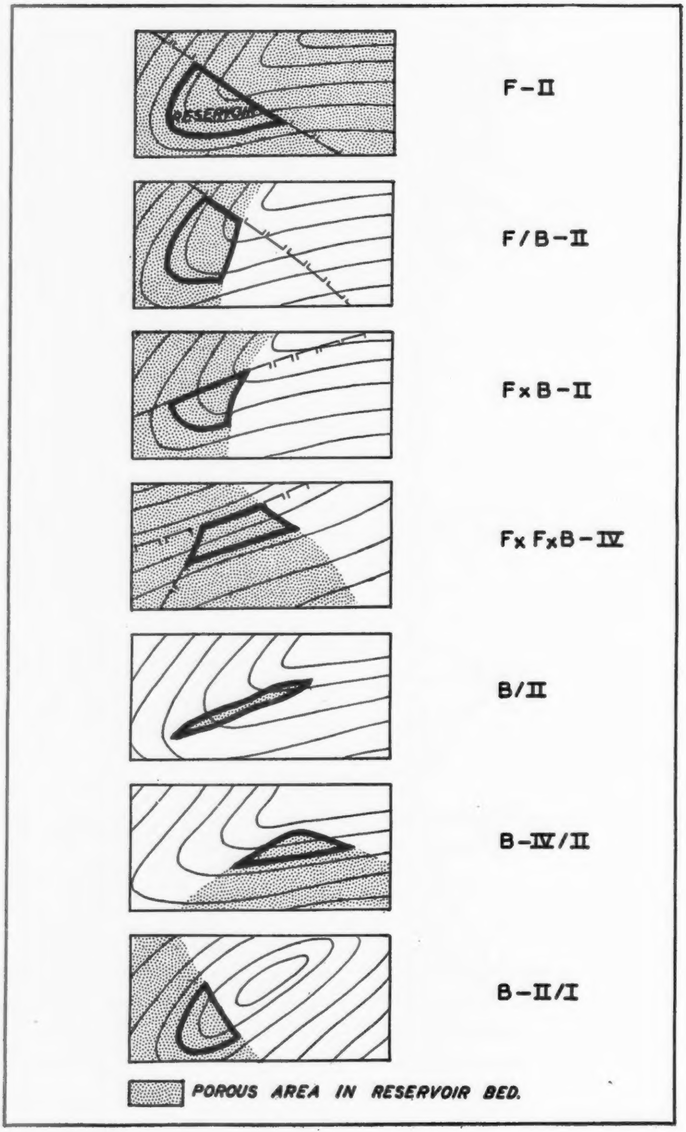


FIG. 3 RESERVOIR SYMBOLS

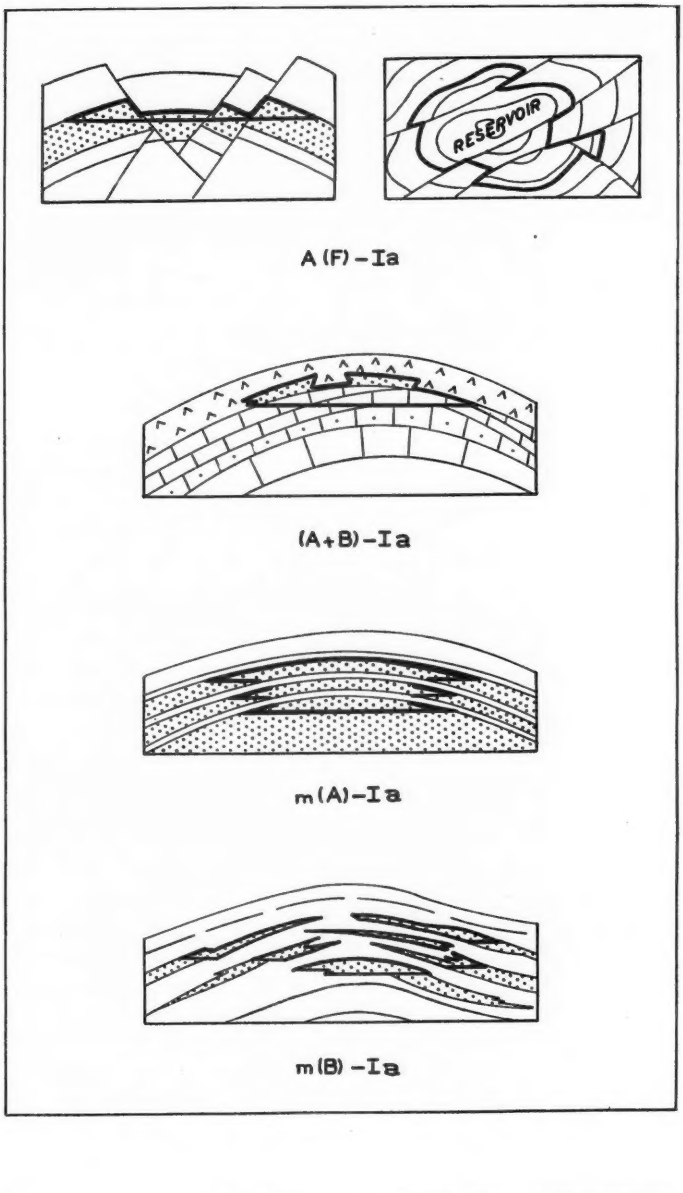


FIG. 4 COMPOSITE & COMPLEX RESERVOIRS

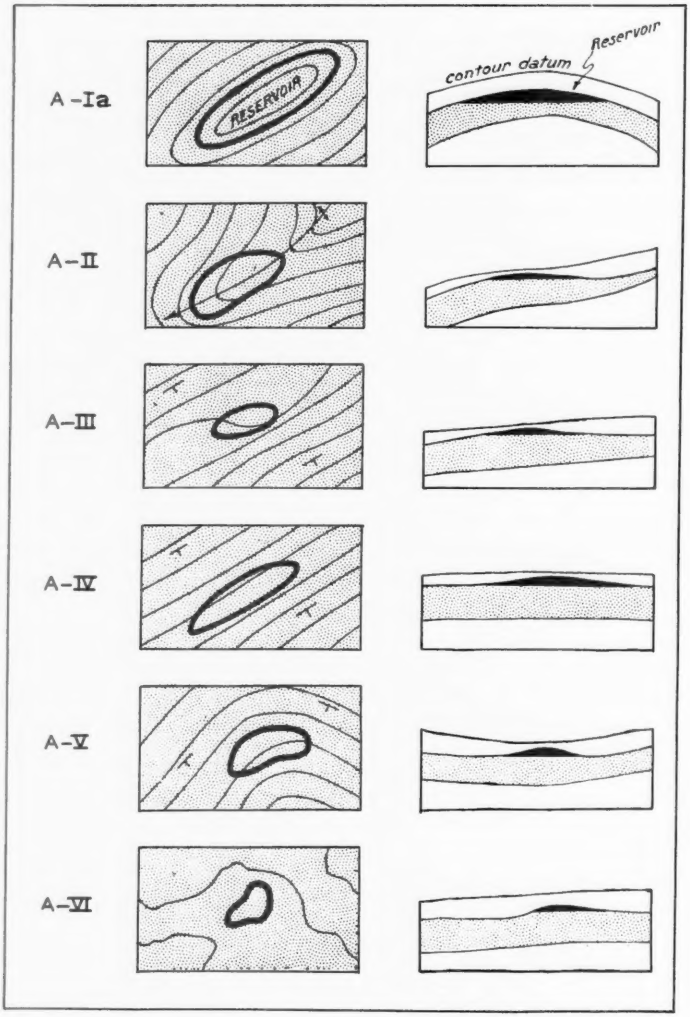


FIG. 5 SIMPLE CONVEX TRAP RESERVOIRS
(IN PLAN & NE-SW LONGITUDINAL SECTION)

SIMPLE CONVEX TRAP RESERVOIRS

The reservoirs in this group show a simple convex surface that may be caused by structural deformation or by combination of structural deformation and differential thickness in porosity conditions or by differential porosity alone. The definition does not depend on the geological reasons for the nature of differential porosity. This may be due, for instance, to irregularity in depositional thickness of a porous bed, to progressive lateral gradation from permeable to impermeable zones, such as from sand to silt or shale, to differential cementation, or to differential solution, as in limestone reservoirs.

Figure 5 shows the entire series of fundamental types in their respective structural environments, as indicated by the contours. Reservoir A-Ia, the 100 per cent structural type of this group, is restricted to the culminations of anticlines or domes. In contrast, the convexity in the surface of Reservoir A-VI, the 100 per cent stratigraphic type, is entirely the result of differential thickness in the reservoir bed. This reservoir can therefore occur in an area showing no structural deformation whatsoever.

In the intermediate types, A-II to A-V, structural and stratigraphic control are reciprocal. In the salient and terrace types, A-II and A-III, the top of the reservoir rises stratigraphically in down-structure direction which, together with the available structural bending, provides the convex reservoir surface. In the monoclinal type, A-IV, the structural influence is reduced to tilting, and porosity must "build up" along the strike as well as in downdip direction to make this reservoir possible. In the synclinal type, A-V, the structural contribution is reduced still further and the convex surface of the reservoir is due to a stratigraphic rise in porosity from nearly all directions.

Figure 6 shows the kind of relation between structure and the top of the reservoir bed that is necessary to produce the convex surface for the reservoirs A-II to A-V. The thin contours in each example are the subsurface contours of the structural environment, and the dotted lines are isopach contours of the interval between the structural marker and the top of the reservoir bed or the top of porosity. The heavy contours, the resulting subsurface contours on the top of the reservoir, show the area of closure. Note that the interval between the structural contours and the top of the reservoir bed has to decrease in a downdip direction to effect such closures. This graphic procedure is a convenient method to determine the position of these reservoirs relative to the structure of the area and to forecast their limits during development.

Reservoir A-Ia is the classical anticlinal type. Reservoirs A-II to A-V are typical for areas of gentle warping where the low rate of dip can be overcome by the rate of differential thickening in the reservoir beds. Reservoirs A-IV, A-V, and A-VI receive little attention in the systematic search for petroleum reserves, because of the lack of adequate exploration methods for locating these types. Nevertheless, in areas where irregular thickness of strata is typical, as, for in-

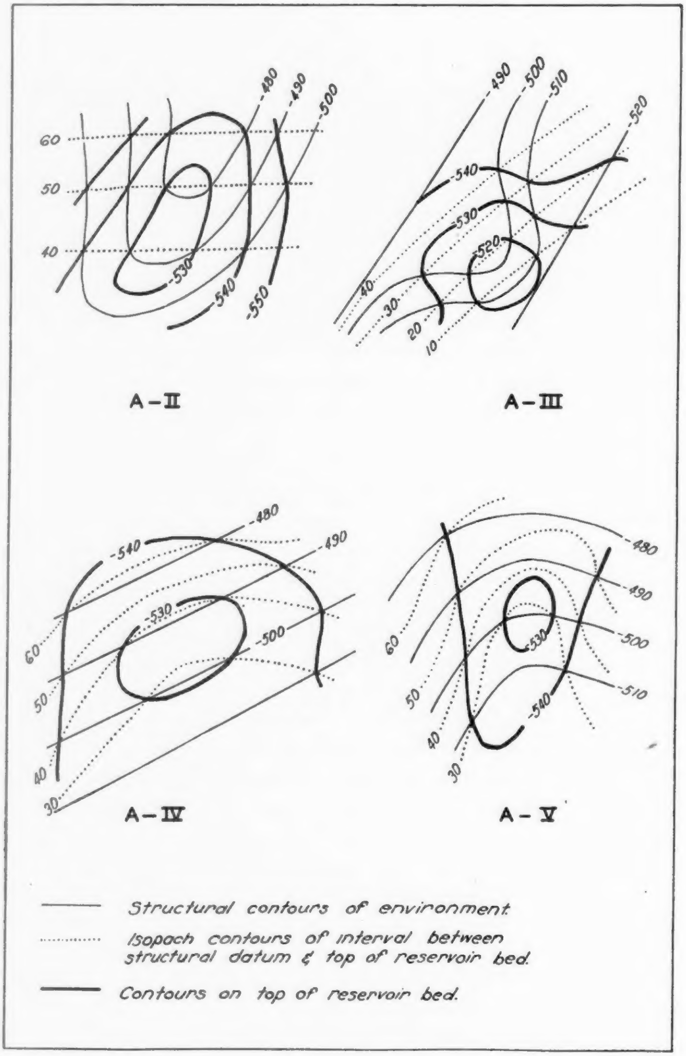


FIG. 6 SUBSURFACE RELATION OF CONVEX TRAP RESERVOIRS

stance, in sequences that originated from near-shore deposition, the chances of finding Simple Convex Trap Reservoirs in monoclinal and synclinal structural environments of low relief should be quite fair. However, only the most comprehensive coordination of all stratigraphic and regional criteria can lead to the discovery of such reservoirs at the present time.

The "4,300-foot" productive sand in the Hull-Silk field, Texas, is an example of an A-II reservoir.[11]

Numerous limestone reservoirs, including types with solution porosity, belong in the A group. In fact, secondary porosity in massive zones of limestone and in areas of low structural relief is apt to give rise to any type of A reservoirs. To identify them with this group, the zone of porosity must, however, extend in all directions beyond the limits of the reservoir to permit a continuous edge-water limit, for example, Goldsmith pool, West Texas,[12] A-Ia.

Cavernous limestone reefs, whose origin is not necessarily connected with structure, display many spectacular petroleum reservoirs of the A-VI type, for example, Tampico-Southern fields (Golden Lane) at thec rest of a barrier reef.[13]

Also, reservoirs in the apex of cavernous cap rock of shallow piercement-type salt domes are in the A group under the designation A-Is (Cap rock).

COMPOSITE CONVEX TRAP RESERVOIRS

These are convex trap reservoirs extending across several structural units, as already described in the discussion of the morphological reservoir varieties (Fig. 4). They are particularly well represented on the deep-seated salt domes of the Gulf Coast, for example, Eola field, A(F)-Ia.[14]

COMPLEX CONVEX TRAP RESERVOIRS

These reservoirs, also shown in Figure 4, are productive intervals composed of separate productive units. They are typical for the Los Angeles and Ventura basins in California, for example, Santa Fe Springs field[15] and Long Beach field.[16]

Santa Fe Springs contains several distinctive groups of complex reservoirs of the m(A)-Ia type. The Long Beach structure, complicated by faults, has a productive interval extending from 2,700 feet to more than 9,000 feet in depth. As a whole, the reservoir can be regarded as a Complex Convex Trap Reservoir modified by faulting, m(A/F)-Ia. From production viewpoints, however, this reservoir consists of many separate units, F-I types trapped against the Cherry Hill fault

[11] E. I. Thompson, "Hull-Silk Oil Field, Archer County, Texas," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol. (1941).

[12] A. Young, M. David, and E. A. Wahlstrom, "Goldsmith Field, Ector County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 10 (1939).

[13] J. M. Muir, *Geology of the Tampico Region, Mexico*, Amer. Assoc. Petrol. Geol. (1936).

[14] F. W. Bates, "Geology of Eola Field, Avoyelles Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 7 (1941).

[15] H. E. Winter, "Santa Fe Springs Oil Field," *California Div. Mines Bull. 118* (1943).

[16] H. P. Stolz, "Long Beach Oil Field," *ibid.*

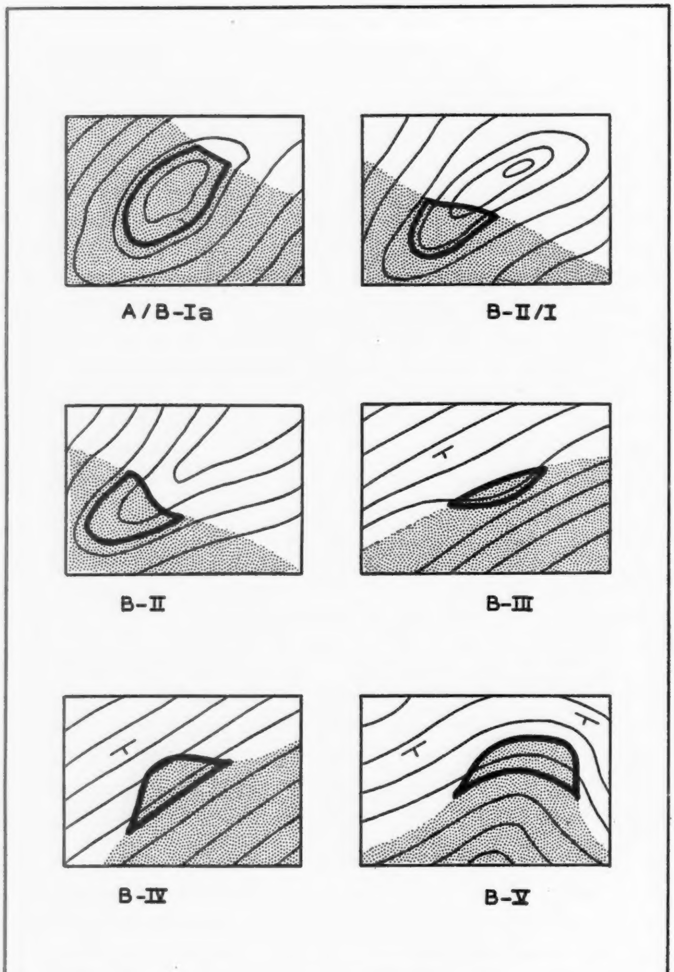


FIG. 7 PERMEABILITY TRAP RESERVOIRS

and A/F-Ia types in the crest of the structure, each with separate encroachment of water and individual behavior in production.

B. PERMEABILITY TRAP RESERVOIRS

Typical reservoirs in this group differ from the Convex Trap Reservoirs in that the edge-water limit is interrupted at the updip side of the reservoir area and replaced by the impermeable barrier which results from the lateral disappearance of permeability in the reservoir bed. In culminations of anticlines and domes, where the complete structural closure does not require any additional trapping agency, permeability barriers are only incidental, modifying Simple Convex Trap Reservoirs (A/B-Ia), (Fig. 7). Since lateral gradation in permeability is a common phenomenon, A/B-Ia reservoirs are frequent, for example, Montebello field, California.[17] In order to form the typical Permeability Trap Reservoirs, B-II/I, B-II, or B-III (Fig. 7), the updip limit of effective porosity must cross the axis of the anticline or of the structural nose or pass diagonally across the terrace. In the monoclinal reservoir, B-IV, the edge of porosity has to form a salient pointing updip; on a plunging syncline, permeability must disappear in all updip directions to produce a synclinal reservoir B-V. The B-VI reservoir can be discounted as a type, except for a lenticular B-VI variety mentioned in a subsequent paragraph.

Reservoirs B-II, B-III, and B-IV on structural salients, terraces, and monoclines are common. Also, the synclinal type, B-V, deserves consideration since plunging syncline environments are abundant and connected with many types of structural systems. Such environments occur on the sides of structural salients, between salients of minor and major structural systems, between *en échelon* anticlinal folds, between the branches of bifurcating anticlines, on the flanks of folds crossing regional monoclines, and along hinge faults (Fig. 8).

Many permeability traps show differential thickness in porosity over the entire reservoir area, thus exhibiting "simple convex trap" affinities. Reservoirs controlled by such traps are therefore modified B/A types, as illustrated in Figure 9, and of some importance. In comparing the B-II reservoir with the B/A-II reservoir, the former shows an abrupt permeability barrier, and a reservoir top and edge-water limit which are essentially parallel with the subsurface contours. In the B/A-II reservoir the thickness of the reservoir bed increases gradually across the reservoir area and the edge-water limit therefore does not conform with the structural contours, which differentiates all B/A types from the corresponding B types. The A-II reservoir added on Figure 9 occurs in a reservoir bed that is identical with the one containing the B/A-II reservoir, but, on account of a smaller size in the accumulation, the A-II reservoir does not extend into the permeability trap and is confined to the smaller convex trap. One significant conclusion can be drawn from this, namely, that under certain conditions negative evidence for a Permeability Trap Reservoir does not quite preclude the

[17] H. P. Stolz and A. F. Woodward, "West Montebello Area of Montebello Oil Field," *California Div. Mines Bull. 118* (1943).

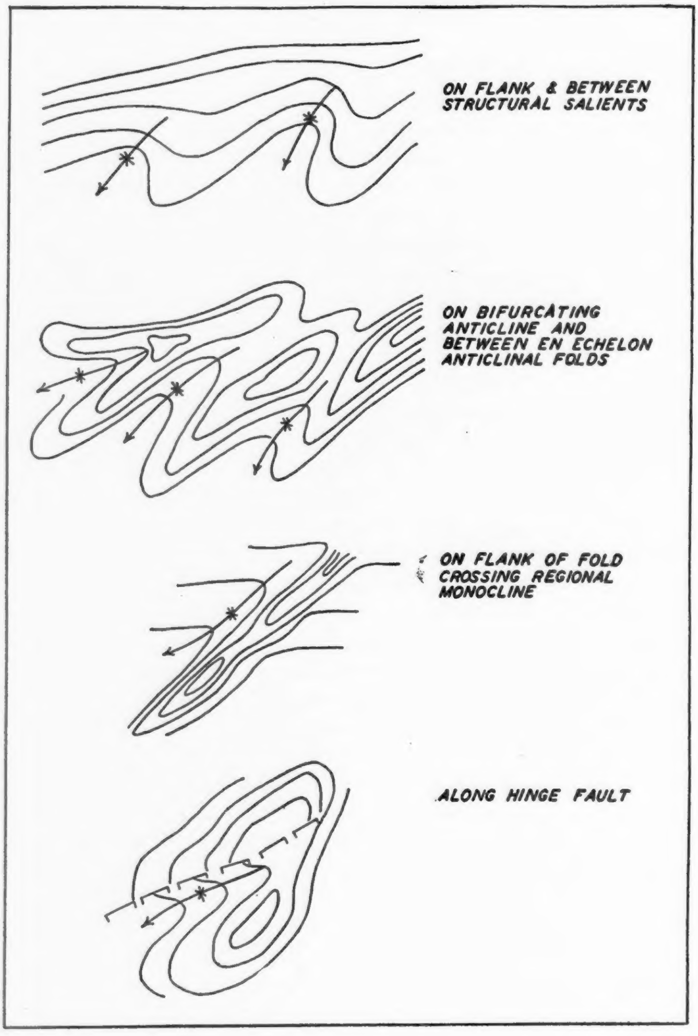


FIG. 8 PLUNGING SYNCLINAL ENVIRONMENTS

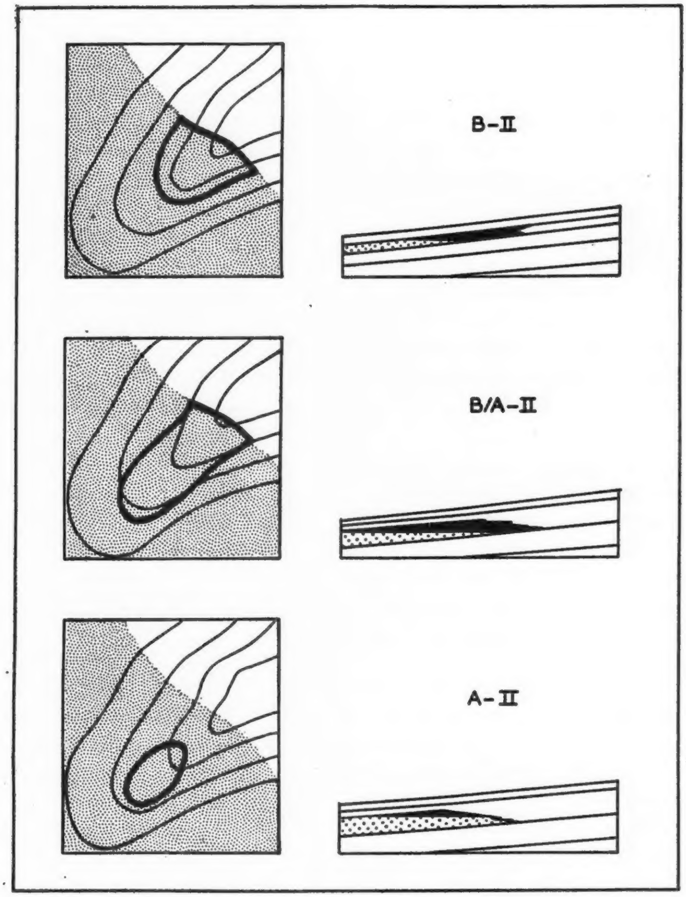


FIG. 9 RELATION BETWEEN B, B/A & A RESERVOIRS

presence of a Simple Convex Trap Reservoir in the same reservoir bed and in the same structural environment.

The most numerous permeability traps are due to change in texture or sorting, or to change in lithology, or to influence of cementation or solution. The effects of these phenomena are not sharply separable and are in some cases complementary. However, in all cases they display about the same manner of a more or less abrupt lateral change in porosity. The term "feather-edge" porosity is commonly used in this connection and the name "Feather-Edge Porosity Reservoirs" is proposed for the reservoir family whose traps are caused by the foregoing conditions.

In rather exceptional instances Permeability Trap Reservoirs are limited in all directions by disappearance of permeability and then conform to isolated lenticular areas of permeability. Such conditions can be due to normally interbedded porous lenses, to erratic inclusions of porous rock, or to lenticularity in permeability conditions. The latter may be caused by variation in texture, variation in cementation, restriction of continuity on account of cross-bedding, or in connection with secondary solution, as in limestones. Reservoirs located in such isolated, lenticular zones of permeability may be called "Lenticular Reservoirs."

Other permeability traps are formed by impregnation of the reservoir bed with asphalt or solid hydrocarbons which seal off porosity or by fracturing and brecciation of impervious rocks or, very exceptionally, by metamorphosis of beds at intrusive volcanic contacts where local porosity can result from volume shrinkage.

The aforementioned individual families of Permeability Trap Reservoirs are considered sufficiently important to warrent further discussion.

Ba—FEATHER-EDGE POROSITY RESERVOIRS

1. *Feather-Edge porosity reservoirs in sands.*—The lithological change from sand to shale, clay, or silt, accompanied by a change from sandy texture to fine clay or silt texture, is the cause for the most common permeability traps. The same effect can result from a change in the degree of sorting, when well sorted sands grade into zones where particles of clay or silt fill the voids between the sand grains or even where a coarse sand grades into one of very fine texture. The conditions are then described as: shaling-out, silting-up, fingering-out, lensing-out, pinching-out, gradation into argillaceous or silty sand, *et cetera.* Under the concept of "pinching-out" of a sand, the question arises as to the separation of Feather-Edge Porosity Reservoirs from the Pinch-Out Trap Reservoirs. This is possible by confining the latter to stratigraphic layers that actually disappear at the edge of the reservoir, either on account of non-deposition or erosion, which is determinable from subsurface correlation by the indication of convergence of beds or of angular unconformities. On the other hand, the stratigraphic zones containing the Feather-Edge Porosity Reservoirs do not show convergence of a degree that would account for the disappearance of the reservoir bed. Under such

conditions subsurface interpretation from good subsurface records disclose that the apparent "pinching-out" of porosity is mostly due to gradation. However, some difference in intervals may be noticeable because of the effect of differential compaction between sand and shale.

The most typical feather-edge porosity conditions in sands are found in beds which originated under marginal marine sedimentation, such as delta and shoreline deposits. The Texas-Louisiana Gulf Coast offers numerous examples of reservoirs in beds formed in stratigraphic environments of this nature, for example, University field, Louisiana,[18] with several A/Ba-Ia reservoirs and Lopez field in Texas,[19] Ba-IV.

In calcareous zones, cementation of sands is rather general. The degree of cementation may laterally increase and reduce the permeability to the point of a permeability trap, and Feather-Edge Porosity Reservoirs due to this cause are not uncommon. Otherwise, this trapping effect is in many cases an incidental factor. The cementing material is ordinarily calcareous, rarely siliceous, and, exceptionally, ferruginous (siderite, iron oxide, *et cetera*). Also, anhydrite is encountered as cementing agent, for example, in Permian sand reservoirs in West Texas and New Mexico.

Finally, many modified B/A types are represented among Feather-Edge Porosity Reservoirs. The Cross Cut-Blake district in Texas[20] appears to have a variety of reservoirs ranging from A/Ba-Ia to Ba/A-II/I and Ba/A-IV/I.

2. *Feather-edge porosity reservoirs in limestones.*—Limestones with any type of porosity are apt to give rise to Feather-Edge Porosity Reservoirs with traps produced by lateral gradation from porous to non-porous limestones, for example, Noodle Creek, Texas,[21] Ba-III, Hugoton gas field, Kansas-Oklahoma,[22] Ba-IV.

Reasons for traps are numerous, such as: (1) change in texture from granular, oölitic, or fragmental to dense crystalline, (2) boundaries of solution action, (3) lithologic change from porous limestone to tight sandy limestone, or from porous dolomitic limestone to dense calcitic limestone, or from porous limestone to anhydrite, and (4) secondary cementation of porous zones by calcite or anyhdrite.

Bb—LENTICULAR RESERVOIRS

This family includes reservoirs in porous lenses which are completely enclosed by impermeable formation. The reservoirs are generally characterized by the absence of free water or by an insignificant accumulation of water in low places of the porous lenses. With regard to productive behavior, these reservoirs are, of

[18] M. T. Halbouty, "Stratigraphic Reservoirs in University Oil Field, East Baton Rouge Parish, Louisiana," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol. (1941).

[19] J. B. Best, "Lopez Oil Field, Webb and Duval Counties, Texas," *ibid.*

[20] E. D. Klinger, "Cross Cut-Blake District, Brown County, Texas," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol. (1941).

[21] H. W. Imholz, "Noodle Creek Pool, Jones County, Texas," *ibid.*

[22] J. L. Garlough and G. L. Taylor, "Hugoton Gas Field, Grant, Haskell, Martin, Stevens, and Seward Counties, Kansas, and Texas County, Oklahoma," *ibid.*

course, of the depletion type. No structural control is required for the presence of Lenticular Reservoirs, and the environment indicator is therefore shown as an incidental factor of the reservoir symbol, for example, Bb/I, Davis sand lens, Hardin field, Texas.[23]

The most outstanding types in this family are the Shoestring Sand Reservoirs of the Mid-Continent region, occurring in areas without structural relief, Bb/VI. The reservoirs are located in sands of Pennsylvanian age variously interpreted as beach, off-shore bar, and channel-fill deposits. The actual reservoir limits are formed either by the shale boundaries or by gradation in the sorting of the sands; differential sorting also influences their productivity, for example, Burbank, Oklahoma; Bush City and Chanute, Kansas;[24] *et cetera*, Bb/VI.

Certain gas reservoirs in narrow, winding belts of sand as found in the Appalachian petroleum region are classified as Lenticular Reservoirs, for example, Berea sand trend, West Virginia,[25] which crosses a system of gently folded structures, Bb/I-V. In this trend accumulations of oil are trapped below the gas layer at structurally low points where the sand belt bridges synclinal depressions. Such oil pools belong to the typical and much debated synclinal oil reservoirs of the Appalachian province, Bb/V (Fig. 9a).

Other restricted porous complexes may provide conditions of Lenticular Reservoirs where favorably located with respect to source beds or to channels of migration, as, for instance, erosion remnants, erosion pockets, or detrital material on unconformities like the Sooy conglomerate on the Central Kansas uplift, for example, Wherry pool, Bb/IV.[26] Erratic igneous reservoir rocks are found in petroleum provinces in volcanic flows or sills with porosity that may be primary or due to fracturing or decomposition. Petroleum accumulations in such igneous rocks are classified in the family of Lenticular Reservoirs when only small quantities of free water are present, for example, serpentine fields near the Balcones fault zone, Texas, Bb/IV.[27]

Finally, if a petroleum reservoir occurs in the porous tectonic breccia of an overthrust plane, the chances are that such a reservoir is completely sealed by impervious formation, and that it belongs, therefore, to the Lenticular Reservoirs (Bb/I or Bb/IV).

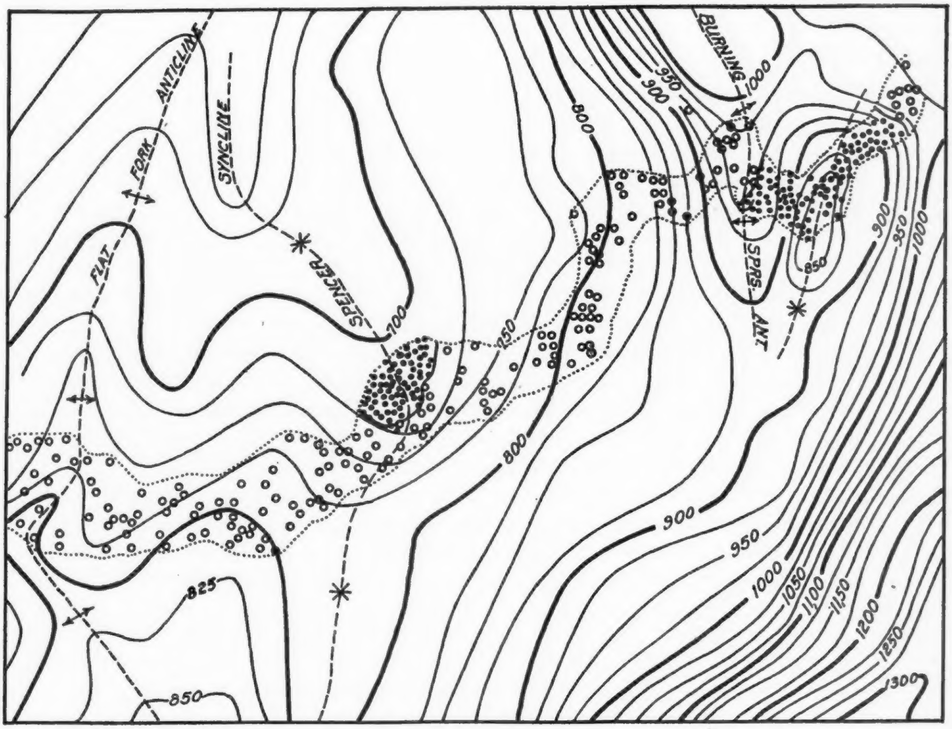
[23] S. R. Casey and R. B. Cantrell, "Davis Sand Lens, Hardin Field, Liberty County, Texas," *ibid.*

[24] N. W. Bass, *op. cit.*
H. H. Charles, "Bush City Oil Field, Anderson County, Kansas," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol. (1941).
W. R. Dillard, D. P. Oak, and N. W. Bass, "Chanute Oil Pool, Neosho County, Kansas," *ibid.*

[25] E. T. Heck, "Gay-Spencer-Richardson Oil and Gas Trend, Jackson, Roane, and Calhoun Counties, West Virginia," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol. (1941).

[26] H. E. McNeill, "Wherry Pool, Rice County, Kansas," *ibid.*

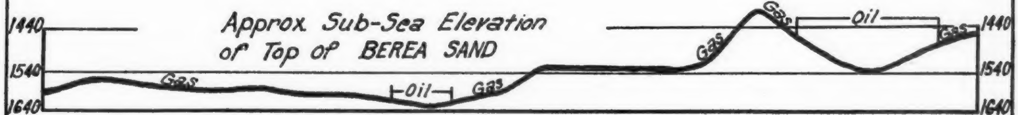
[27] E. H. Sellards, "Oil Fields in Igneous Rocks on Coastal Plain of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 8 (1932).



BEREA SAND BELT, GAY-SPENCER-RICHARDSON TREND
STRUCTURE ON WASHINGTON COAL
(AFTER RAY V. HENNEN & C.E. KREBS)

∘ GAS WELLS
• OIL WELLS

0 1 2 3 4 Miles
Scale



CROSS SECTION

(FROM "STRATIGRAPHIC TYPE OIL FIELDS," AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, 1941)

FIG. 9a SYNCLINAL OIL RESERVOIRS

Bc—RESERVOIRS IN ZONES OF FRACTURE

In hard limestone, sandstone, chert, or siliceous shale, fracturing may open a network of fissures and thereby produce a porous and permeable rock which can serve as reservoir rock. If the fissuring is general and extensive, as, for instance, in folded limestone, the resulting reservoir rock may lend itself for Simple Convex Trap Reservoirs of the A-Ia or A/F-Ia types, for example, in Iranian oil fields. Exceptionally, fractured siliceous shale or chert is found as reservoir rock in strongly folded anticlines, for example, Spellacy anticline, Midway field, California, A-Ia.[28] On the other hand, where fissuring and accompanying permeability are restricted to certain zones or patterns of fracturing, the boundaries of these zones form permeability traps, as in the Northern fields of the Tampico region, Mexico, located on a large regional uplift and producing from faulted and fractured Cretaceous limestones. The location pattern of the producing wells and subsurface observations indicate that the oil was concentrated along rather definite zones of faulting and fracturing. Essentially, permeability appears to be confined to these zones and thus limited by the boundaries between fractured and undisturbed limestone. To what extent solution action contributed to the porosity is not known, but it is justified to classify this reservoir separately because of the distinct relation of the productivity to the pattern of fracturing, Bc-Ia.[29]

Bd—RESERVOIRS WITH ASPHALTIC SEALS

At least one major oil field belongs with this reservoir family, namely, East Coalinga, Bd-II, in the San Joaquin Valley, California. The field is located on a structural nose with the outcrop of the producing Temblor sands a short distance updip from the productive area. The structure is thus open, and the oil reservoir is mainly protected by some heavy residual oil and asphalt which impregnated the sand between the reservoir and the outcrop. However, a stationary oil-water contact suggests that the edge water had reached a level of equilibrium due to regional hydrostatic conditions. This is probably the principal reason why the large Coalinga reservoir could maintain itself under the weak protection of an asphaltic seal.

Many less important accumulations of heavy oil are trapped by impregnation of residual asphalt at or near outcrops of structurally open reservoir beds. Cakes of asphalt deposited from petroleum that seeped to the surface or asphalt impregnation in the reservoir bed below the outcrop trapped the oil which followed. Such reservoirs occur particularly in strongly tilted beds in the eroded cores of steep anticlinal uplifts, or on their flanks, Bd-IV/I.

[28] T. Hillis and W. T. Woodward, "Williams and Twenty Hill Areas of the Midway Sunset Oil Field," *California, Div. Mines Bull. 118* (1943).

[29] J. M. Muir, "Limestone Reservoir Rocks in the Mexican Oil Fields," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934).

C. PINCH-OUT TRAP RESERVOIRS

This group is distinguished from the Convex Trap Reservoirs by the pinching-out of the reservoir bed at the updip edge of the reservoir area, whereby the edge-water boundary is partly replaced by a margin formed by the pinch-out. The distinction from the Permeability Trap Reservoirs is made by restricting the Pinch-Out Trap Reservoirs to types located in such stratigraphic intervals or zones which actually wedge out. This can be decided from subsurface correlation by the indication of angular unconformity or convergence of beds at the same rate as the reservoir layer decreases in thickness, so that there is no doubt that the layer is actually terminated. Evidently the most important subsurface consideration in connection with Pinch-Out Trap Reservoirs is the establishing of the complete stratigraphic sequence for the area under consideration. This information is essential to determine at any locality whether a well has penetrated a normal section or whether downdip pinch-out trap possibilities are suggested by the absence of certain zones. There are few, if any, areas where such considerations are not called for.

In the types C-II/I, C-II, and C-III the margin of the pinch-out crosses the axis of the respective structural features (Fig. 10). In the monoclinal types, C-IV, the margin has to form a salient pointing updip on the monocline, and in the synclinal type, C-V, the reservoir bed must pinch out in all updip directions. Such symbols as C-IV/I and C-IV/II indicate a Pinch-Out Trap Reservoir in a strictly monoclinal position on the flank of an anticline, or on the side of a structural salient, where the margin of the pinch-out does not cross the axis.

Pinch-out characteristics are connected with depositional conditions and with various features due to erosion, and the Pinch-Out Trap Reservoirs are divisible into three families of importance, namely, Ca—Depositional Pinch-Out Reservoirs in stratigraphic wedges, Cb—Truncated Pinch-Out Reservoirs in layers truncated by typical erosional unconformity, Cc—Overlap Pinch-Out Reservoirs in basal conglomerates and in detrital zones associated with planes of unconformities.

Ca—DEPOSITIONAL PINCH-OUT RESERVOIRS
Cb—TRUNCATED PINCH-OUT RESERVOIRS

These two reservoir families are discussed together. In a broad sense, the "depositional pinch-out traps" occur in stratigraphic wedges which represent zones that show convergence by gradual thinning of their members and by successive dropping-out of the members in periodical or irregular order, in effect causing a number of unconformable breaks. This is in contrast to stratigraphic zones abruptly cut off by angular unconformities. They contain the "truncated pinch-out traps" sealed by relatively impermeable beds above the unconformity.

Petroleum reservoirs associated with both of these conditions have become very important. However, certain difficulties in the interpretation of unconformity problems and therefore in the distinction between Ca and Cb reservoirs arise

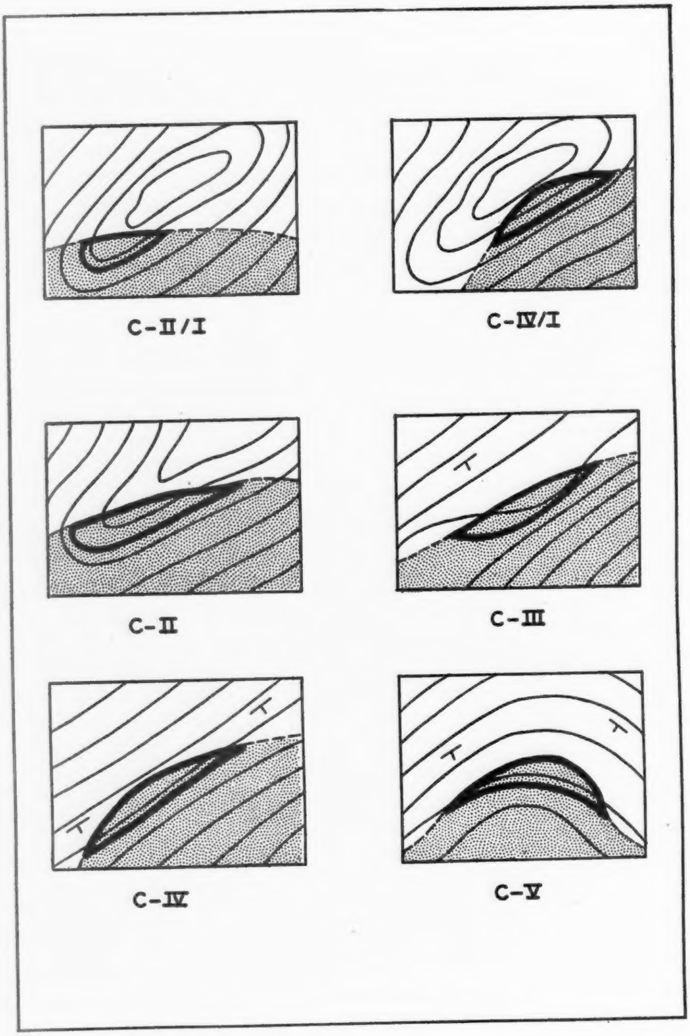


FIG. 10 PINCHOUT TRAP RESERVOIRS

from the dual use of the term "unconformity" as a "surface of either erosion or non-deposition separating two groups of strata." An attempt is therefore made in the following to explain diagrammatically the logical relations between stratigraphic wedge and unconformity conditions and the position of the respective reservoirs. In the section (Fig. 11) the formations shown form three groups.

Upper Group L, constant thickness, continuous
Middle Group M, converging and wedging out
Lower Group N, constant thickness and truncated by erosion

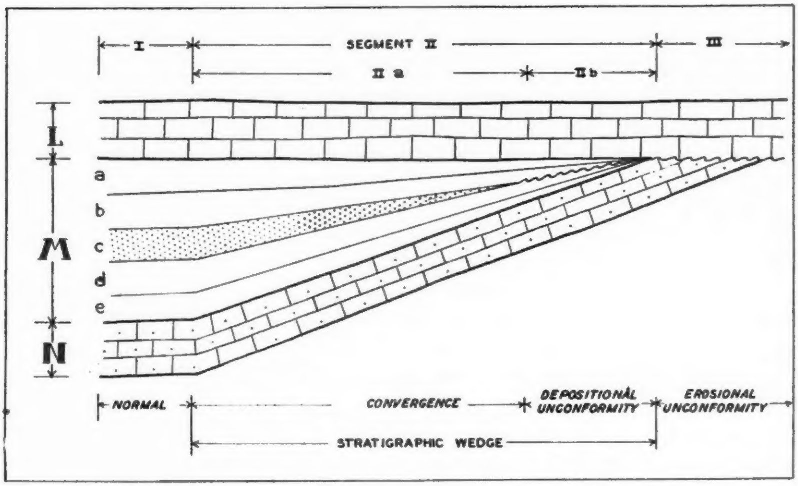


FIG. 11 DIAGRAMMATIC RELATION BETWEEN THE NORMAL STRATIGRAPHIC SEQUENCE, STRATIGRAPHIC WEDGE AND UNCONFORMABLE CONDITIONS.

Horizontally the section is divided into three segments.

Segment I, normal stratigraphic sequence
Segment II, stratigraphic wedge of Group M, *location of Depositional Pinch-Out Reservoirs*
Segment III, Groups L and N meet at an erosional unconformity, *location of Truncated Pinch-Out Reservoirs*

Note that in subsegment IIa, Group M shows thinning by convergence of its subzones but all markers can be traced, while in IIb individual members of Group M gradually drop out at an unconformity until the whole group is pinched out entirely. The possibility of differentiating subsegment IIa from IIb depends on the quality and density of the correlatable markers. In Segment III, Group N does not go out by natural thinning; the break between Group M and N is definitely a plane of erosion, an erosional unconfomity which is angular.

Segment II represents the logical intermediate stage of convergence between the normal regional stratigraphic succession in Segment I and conditions brought about by uplift and erosion in Segment III. Under submerged marine conditions

of deposition, as encountered in connection with petroleum deposits, the structure of Segment II results from the balancing of the rate of sedimentation and the rate of uplift. In the simple case shown on the sketch, the rate of uplift was greater during deposition of the stratigraphic members M-e and M-d, causing regression in sedimentation and smaller during deposition of the members M-b and M-a, causing transgression. If the tectonic movements and deposition were in perfect balance, the interruption in the stratigraphic sequence in the subsegment IIb would be due to non-deposition alone. However, due to exposure between the regression and transgression phases local erosion may have affected this depositional unconformity to a variable extent and it is ordinarily difficult to decide from subsurface data whether the updip edge of a bed that pinches out in a zone of convergence is the original margin or whether it is cut back by erosion. Absence of basal conglomerates or basal detrital zones would be characteristic of unconformities developed under such conditions, since the rock fragments removed by erosive action in subsegment IIb would rather be found scattered through the stratigraphic intervals in the adjoining subsegment IIa where deposition was uninterrupted. Under the circumstances shown on the sketch, such material might be found in the M-c member of IIa.

The presence of traps under the foregoing conditions depends on the relative position of permeable and impermeable beds. As for the evaluation of possibilities for Depositional Pinch-Out Reservoirs located in Segment II of Figure 11, the following may be considered. The M-a member must be impermeable to seal the wedge entirely in an updip direction and to provide favorable possibilities for traps in its lower permeable members. If M-a is permeable and M-b impermeable, only M-c and M-d are protected and suitably trapped if they are permeable. If M-c is the first impermeable member in the wedge, no favorable reservoir conditions will be found in the M group despite its wedge structure, unless sealing is effected by impermeable formation at the base of the L group. The latter condition is also required to produce the traps for Truncated Pinch-Out Reservoirs in Segment III.

The conditions described in the foregoing may occur on a regional scale or on local structures. The East Texas field,[30] as an example of a regional pinch-out trap, is generally described as a Truncated Pinch-Out Reservoir in monoclinal position on the flanks of the large Sabine uplift, Cb-IV. Typical Ca-IV/I and Cb-IV/I (Fig. 12) reservoirs occur on structures like the "buried hill structures" in the Mid-Continent regions, which are the remnants of Paleozoic uplifts more or less levelled off by erosion and then buried under a new blanket of sediments, for example, Oklahoma City field.[31]

In the shallow piercement type salt-dome structures of the Gulf Coast (Fig.

[30] H. E. Minor and M. A. Hanna, "East Texas Oil Field, Texas," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol. (1941).

[31] D. A. McGee-W. W. Clawson, "Geology and Development of Oklahoma City Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 10 (1932).

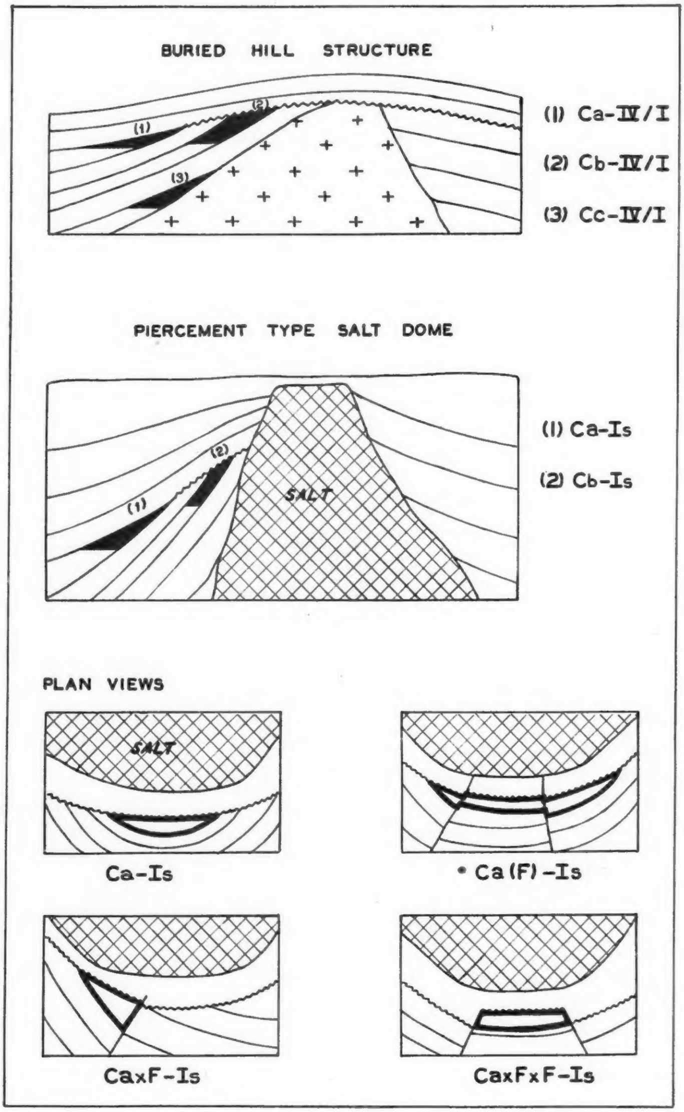


FIG. 12 PINCHOUT TRAP RESERVOIRS

12), the entire set of stratigraphic conditions represented by Segments I, II, and III of Figure 11 may be developed within a short radial distance on the flanks. Reservoirs are situated in sealed sand members pinching out in Segment II (Depositional Pinch-Out Reservoirs, Ca-Is), as well as in sands truncated by erosional unconformity in Segment III (Truncated Pinch-Out Reservoirs, Cb-Is), for example, Jennings field, Louisiana.[32] In addition, the strata flanking the salt plugs are generally cut by radial faults and many pinch-out traps on piercement type salt domes are therefore combined with fault traps, resulting in reservoirs with double traps, triple traps, and composite traps: Ca×F-Is, Ca×F×F-Is, Ca(F)-Is, or corresponding Cb reservoirs, as illustrated in Figure 12.

Cc—OVERLAP PINCH-OUT RESERVOIRS

Reservoirs of this type are found in porous conglomeratic material on regional unconformities or at the base of marine overlaps over a basement complex (Fig. 12). The deep productive zone in the Playa del Rey structure, California, is an example of such a reservoir located in a basal conglomerate which pinches out on the plunge of the Franciscan (basement) core of the uplift,[33] Cc-II/I.

F. FAULT TRAP RESERVOIRS

Normally a reservoir in a fault trap is sealed at the fault plane by impermeable strata placed against the reservoir bed by the action of faulting. However, fault planes lined with thinnest veneers of plastic clay or pulverized fault gouge of low permeability may separate oil reservoirs from water-logged porous sands that lie in juxtaposition. This is particularly noted in shallow, low-pressure, and heavy-oil reservoirs. Furthermore, fine sand of low permeability faulted against coarse sand of higher permeability has been observed to provide a seal at the resulting coarse-fine interface. Such a barrier may break down when the reservoir pressure is lowered by withdrawals allowing water to invade the reservoir across the fault plane.[34] Evidently reservoir pressures and viscosity of oil play a significant part in the problems of fault traps, and apparent sand-to-sand contact at a fault plane need not condemn the chance of trapping, as an effective seal may be present under the conditions mentioned.

It is possible to subdivide most of the numerous Fault Trap Reservoirs as follows (Fig. 13).

F—Fault Segment Reservoirs. *A single fault* acts as barrier in conjunction with structural closure against the fault plane (single trap)

F//F—Fault Block Reservoirs. A pair of more or less *parallel faults* acts as barrier (double trap)

F×F—Fault Wedge Reservoirs. A pair of *intersecting faults* acts as barriers (double trap)

This subdivision is independent of the nature of the faults which may be either

[32] C. B. Roach, "Subsurface Study of Jennings Field, Acadia Parish, Louisiana," *ibid.*, Vol. 27, No. 8 (1943).

[33] L. H. Metzner, "Playa del Rey Oil Field," *California Div. Mines Bull. 118* (1943).

[34] G. S. Taitt, "Sealing Effect of Fault Surfaces," *Jour. Inst. Petrol.*, Vol. 28, No. 222 (1942).

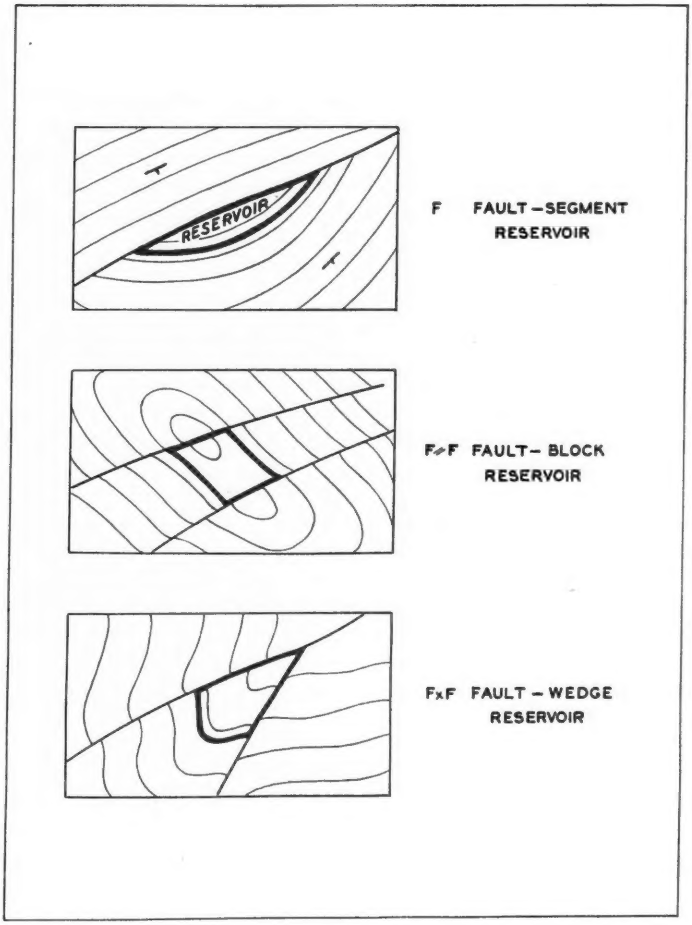


FIG. 13 FAULT TRAP RESERVOIRS

normal or reversed. To designate the type of fault as normal or reversed, if desirable, the additional symbols, *n* for a normal, *r* for a reversed fault, could be used.

F—FAULT SEGMENT RESERVOIRS

The most common of these reservoirs occur on the axes or on the flanks of faulted anticlines, F-II/I and F-IV/I; on faulted structural noses, F-II, and along *en échelon* fault zones on regional monoclines, for example, Mexia zone,[35] F-IV. Strongly folded anticlines are usually disturbed by reversed faults, which are mostly longitudinal and give rise to typical reservoirs located on underthrust flanks, F(*r*)-IV/I (Fig. 14).

Faults are usually incidental trapping agencies in the structural culminations of anticlines and domes. Reservoir areas are either cut short by faults (A/F-Ia, Fig. 14), or a reservoir extends through a number of crestal fault blocks and represents a Composite Convex Trap Reservoir with a common water level A(F)-Ia (Fig. 4). In this latter case the faults have not acted as barriers in the process of adjustment of the accumulation. During the short period of exploitation, however, separate drainage behavior may or may not appear in different blocks.

F//F—FAULT BLOCK RESERVOIRS

Individual reservoirs in traps formed between a pair of more or less parallel faults occur mainly in block-faulted structural regions. Structural units enclosed by such faults are: horsts, grabens, and fault steps. Although the so-called "central graben" is a common structural feature at the apex of faulted anticlines and domes, F//F-Ia reservoirs are quite rare in these structures. The reservoirs which occur in central graben blocks are more commonly restricted to the structural culmination which is ordinarily found inside the "central graben," and are mostly A-Ia or A/F-Ia types.

F×F—FAULT WEDGE RESERVOIRS

This double trap reservoir occurs in anticlinal culminations and domes, F×F-Ia, and at fault zones in monoclinal regions F×F-IV (Fig. 15). The traps are formed by intersection of faults which may be normal or reversed. In deep-seated and semi-deepseated salt domes, fault wedges are common in the intersecting fault patterns and may contain reservoirs which are either separate, F×F-Ia, or part of Composite Convex Trap Reservoirs, A(F)-Ia. In other folds, fault wedges can be formed by intersecting reversed faults, F×F(*r*)-I. The Sargent oil field in California[36] is a Fault Wedge Reservoir at the head of a syncline, F×F-V.

OTHER DOUBLE TRAP AND TRIPLE TRAP RESERVOIRS

A significant series of reservoirs may be derived from the fault-wedge trap if

[35] F. H. Lahee, "Oil and Gas Fields of the Mexia and Tehuana Fault Zones," *Structure of Typical American Oil Fields*, Vol. I, Amer. Assoc. Petrol. Geol. (1929).

[36] J. Michelin, "Sargent Oil Field," *California Div. Mines Bull. 118* (1943).

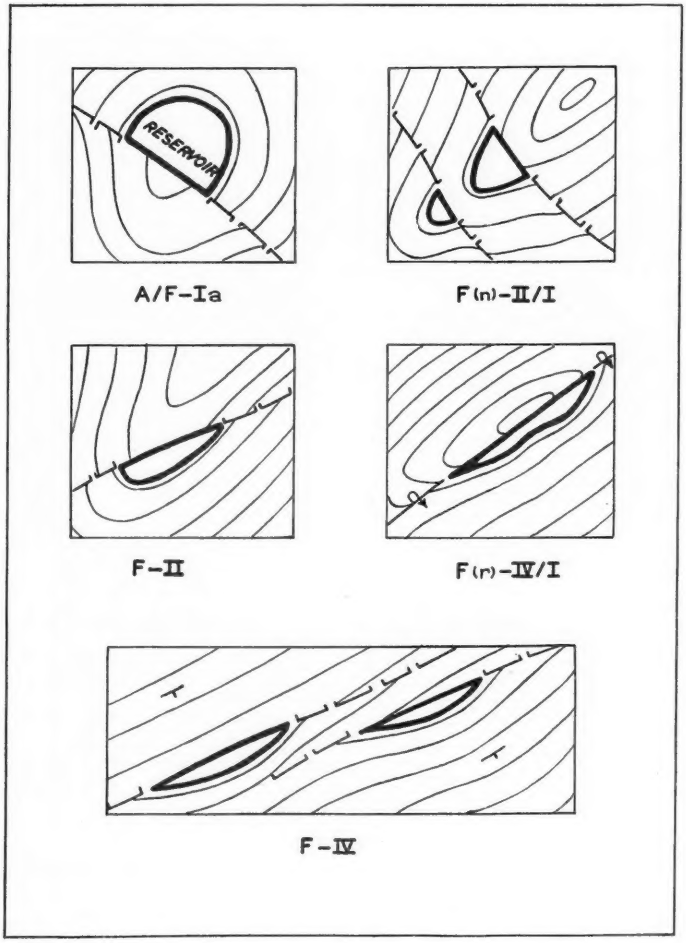


FIG. 14 TYPICAL RESERVOIRS IN FAULT SEGMENTS

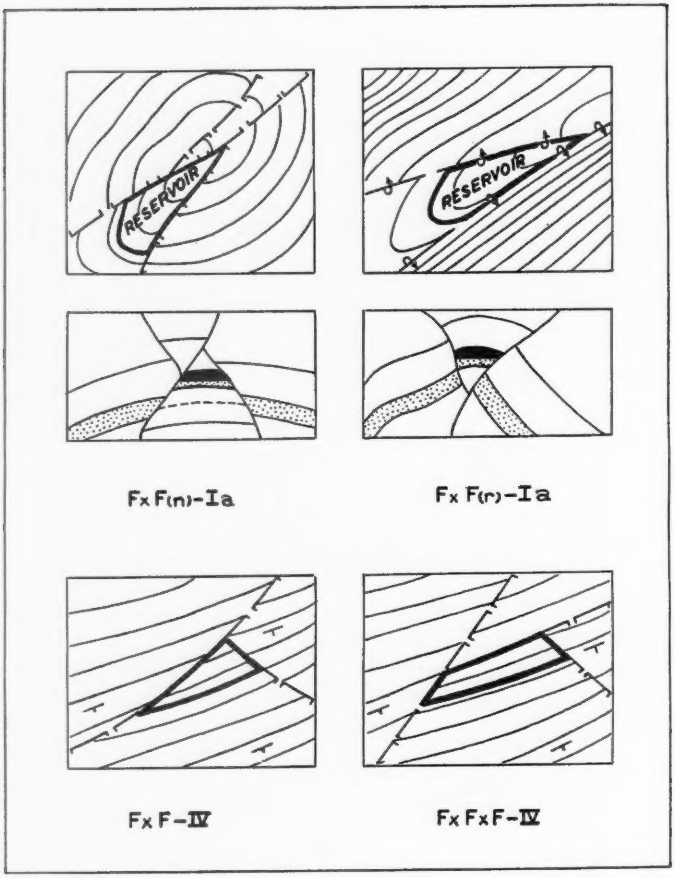


FIG. 15 FAULT TRAP RESERVOIRS
DOUBLE TRAPS AND TRIPLE TRAPS

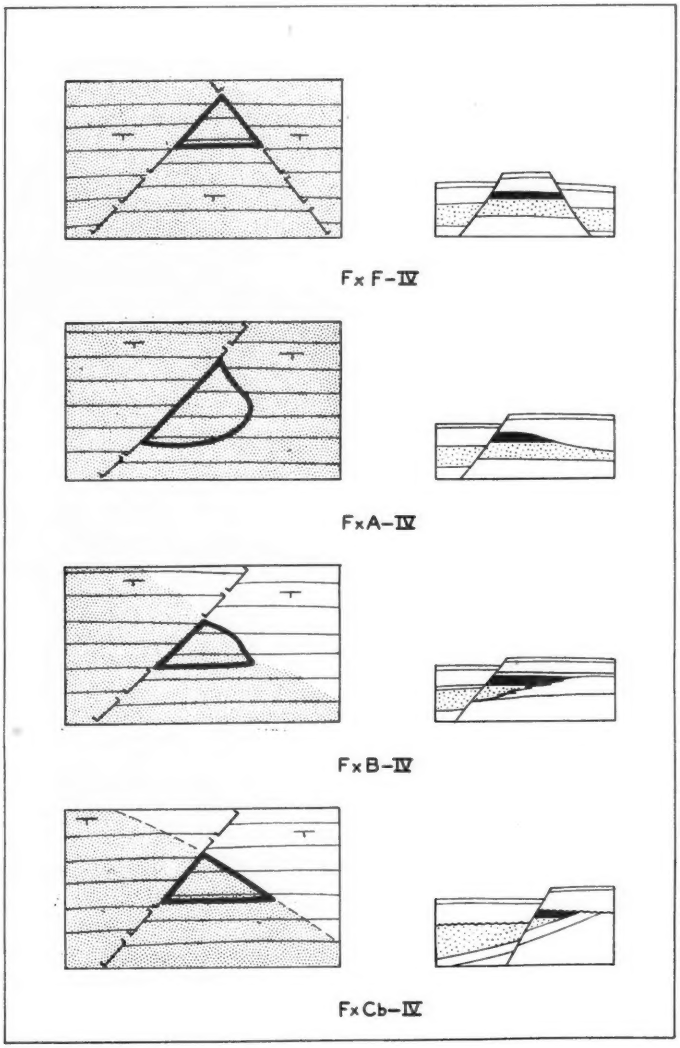


FIG. 16 DOUBLE TRAP RESERVOIRS

the role of one of the faults is replaced by other trap-forming factors, namely, differential thickness, FxA; change in permeability, F×B; or pinch-out, F×C (Fig. 16).

As examples of double trap reservoirs may be cited the O'Hern field in Texas,[37] F×Ba-IV/I, and the reservoir in the Upper Duff zone of the Edison oil field in California,[38] F×Ba-II.

Double trap reservoirs can be fitted into any structural environment. It can probably be shown in many areas condemned for the conventional single trap reservoirs that untested double traps may still be present. This is particularly worth considering for areas where faulting on a regional scale is observed and where, at the same time, potential reservoir beds show marked tendencies for variation in thickness (F×A traps), for changes in permeability (F×B traps), or for pinching-out (F×C traps).

Combined traps of still higher orders, for example, triple fault traps (Fig. 15) are known to occur in monoclinal regions intersected by regional fault patterns, as in the Luling field, Texas,[39] F×F×F-IV.

G. PIERCEMENT TRAP RESERVOIRS

The effect of tectonic piercement is chiefly observed in piercement type salt domes with plugs of rock salt and in diapiric anticlines with cores of plastic material, clay, or salt. For classification purposes, the distinction between the two kinds of uplifts is made by letters attached to the structural environment indicator, Is for salt dome and Id for diapiric anticline. Some igneous plugs (Ii) piercing sedimentary beds are involved in the accumulation of petroleum, for example, in the Sutter Buttes gas field in California[40] on an uplift with a porphyry plug, G-Ii.

PIERCEMENT TRAP RESERVOIRS ON PIERCEMENT TYPE SALT DOMES

These reservoirs occur in beds abutting against a plug of impervious rock salt, or in places, against a clay body which was pushed up from greater depth with the salt plug. Such clay masses may still be in some connection with the flanking beds and are then usually called "drag zones," or they may be completely disconnected sheets covering parts of the salt plug (Fig. 17).

The structural configuration of the beds carrying the Piercement Trap Reservoirs is partly due to uplift that took place prior to the actual stage of piercement. Not all salt cores are thrust through the exact center of the pre-existing uplift, and not all are vertical, or perfectly rounded on the utside. Consequently, most structural contours of the flanking beds are not parallel with the periphery of the

[37] D. G. Barnett, "O'Hern Field, Duval and Webb Counties, Texas," *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol. (1941).

[38] E. C. Edwards, "Edison Oil Field and Vicinity, Kern County, California," *ibid.*

[39] E. W. Brucks, "Luling Oil Field, Caldwell and Guadalupe Counties, Texas," *ibid.* (1929).

[40] W. Stalder, "1941 Supplement to Sutter (Marysville) Buttes Development, Sutter County, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 5 (1942).

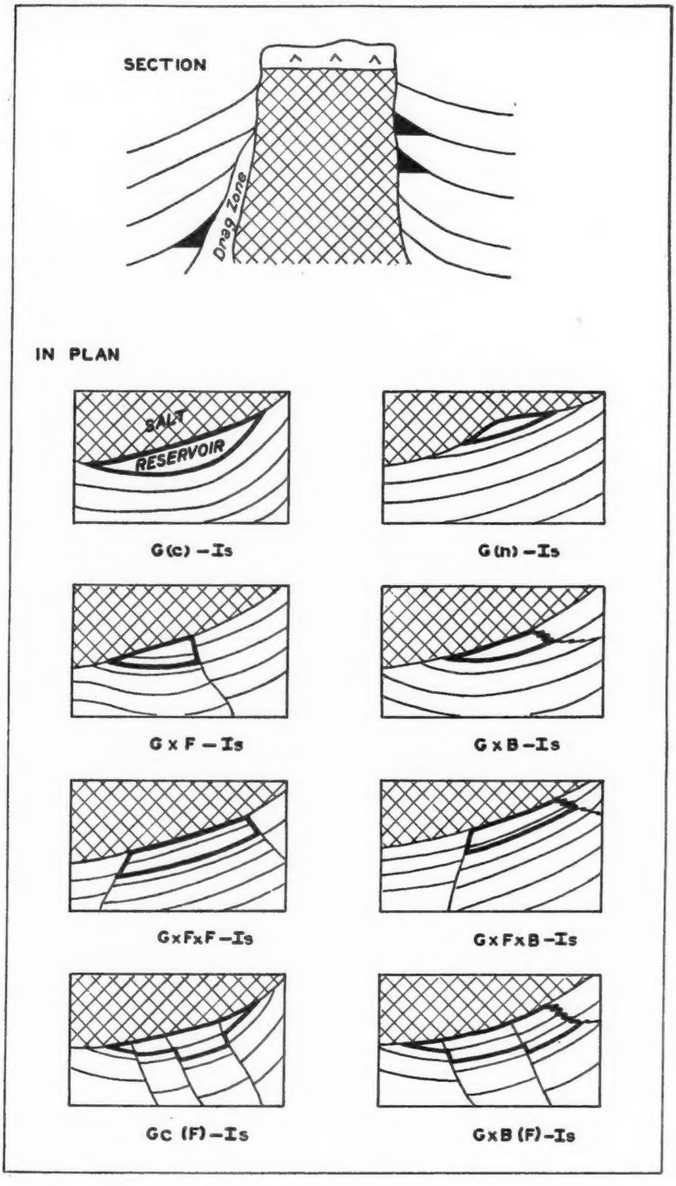


FIG 17 PIERCEMENT TRAP RESERVOIRS ON SHALLOW PIERCEMENT TYPE SALT DOMES

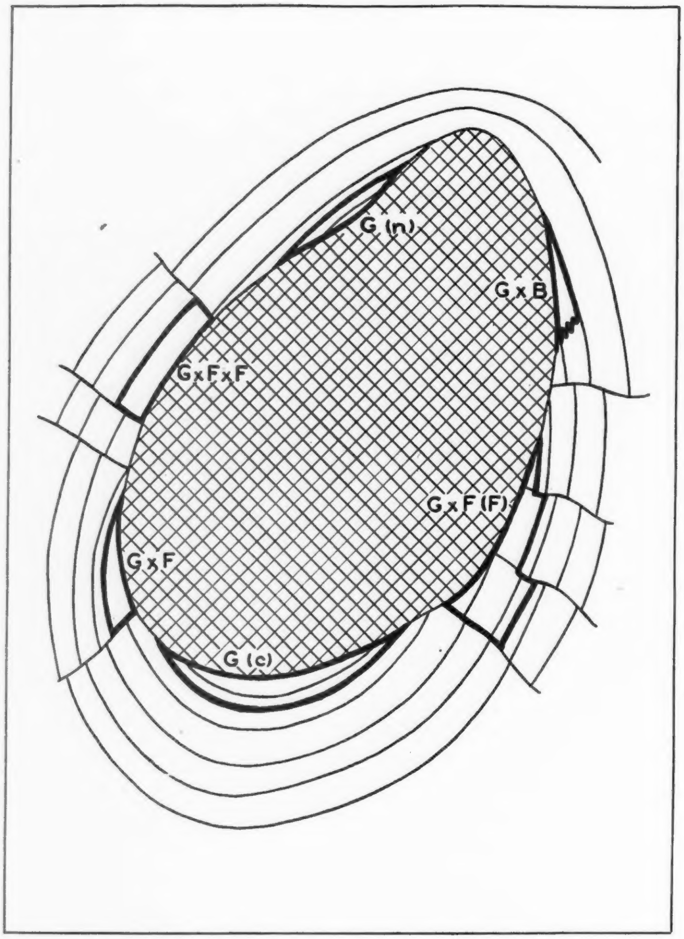


FIG. 18 STRUCTURAL ARRANGEMENT OF PIERCEMENT TRAPS

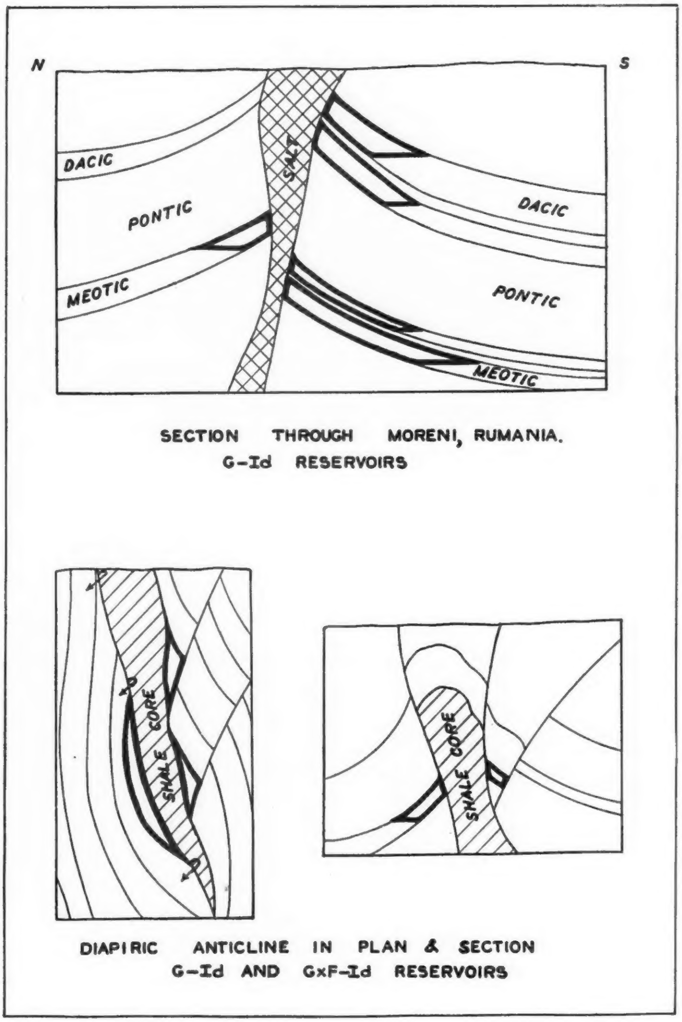


FIG. 19 PIERCEMENT TRAP RESERVOIRS
IN DIAPIRIC ANTICLINES

salt plug (Fig. 18), which is one of the principal factors to be considered in piercement traps. The other factors are radial faulting, a common feature of piercement domes, and local cementation, also referred to as mineralization, originating from solutions which were in contact with the salt core and cap rock. The cementing material is mainly calcite, anhydrite, marcasite, and pyrite.

The following subdivision of Piercement Trap Reservoirs in piercement type salt domes is derived from the foregoing points (Figs. 17 and 18).

1. *Crescent Reservoirs, Gc-Is.* The trap is formed by structural closure of the flanking beds against the salt plug, for example, main reservoir in Anse La Butte, Louisiana[41]
2. *Salt Niche Reservoirs, Gn-Is.* The trap is formed by a recess in the side of the salt plug with the beds rising into this recess
3. *Peripheral Wedge Reservoirs* (double traps)
   (a) G×F—Is, trapped between the salt edge and a radial fault
   (b) G×B—Is, trapped between the salt edge and a permeability barrier caused by local cementation of the reservoir bed
4. *Peripheral Segment Reservoirs* (triple traps)
   (a) G×F×F—Is, trapped between the salt edge and a pair of radial faults which are essential when the structural contours of the flanking beds are parallel with the periphery of the salt plug
   (b) G×F×B—Is, trapped between the salt edge, a radial fault, and a permeability barrier due to local cementation
5. *Composite Piercement Trap Reservoirs.* On account of the general occurrence of radial faults, many Piercement Trap Reservoirs are of a composite type, Gc(F)-Is, *et cetera* (Fig. 17).

PIERCEMENT TRAP RESERVOIRS ON DIAPIRIC ANTICLINES

The term "diapiric anticline" is applied to uplifts pierced by cores of plastic material squeezed up during the process of folding (Fig. 19). Trapping conditions, associated with diapiric cores are similar to those on piercement salt domes, being connected with structural closure against the piercement contact and with intersecting faults. The Moreni field in Roumania is a simple case of a diapiric anticline with a core of rock salt; its reservoirs are of the crescent (Gc-Id) type. More complicated diapiric folds are strongly faulted asymmetric uplifts with thrust faulting and normal faulting on opposite flanks, providing a variety of trapping conditions partly fault traps, partly piercement traps. It may be preferable in such cases to regard the contact with the diapiric core as a regular fault boundary, and all reservoirs would then be classified as Fault Trap Reservoirs.

V. Conclusion

The reservoirs discussed in this article cover the great majority of petroleum reservoirs that are formed under typical geological conditions. A review of very exceptional types might disclose examples which would require further enlargement of the system.

To conclude, Table I lists all types of reservoirs mentioned. The tabulation is based on the principles of classification followed in the study.

1. The logical combination of trap-forming factors which are grouped into trap indicators and structural environment indicators

[41] F. W. Bates and D. B. Wharton, "Anse La Butte Dome, St. Martin Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 8 (1943).

2. Distinction between essential and incidental function of the indicators involved in the traps
3. A morphological division into reservoir varieties derived from the relationships between the trap and environment indicators into
   - Single Trap Reservoirs
   - Double Trap Reservoirs
   - Triple Trap Reservoirs
   - Modified Reservoirs
   - Lenticular Reservoirs
   - Composite Reservoirs
   - Complex Reservoirs
4. A natural division into five reservoir groups based on the trap indicators
   - A. Convex Trap Reservoirs
   - B. Permeability Trap Reservoirs
   - C. Pinch-Out Trap Reservoirs
   - F. Fault Trap Reservoirs
   - G. Piercement Trap Reservoirs
5. Subdivision of reservoir groups according to morphological reservoir varieties, for example
   - Simple Convex Trap Reservoirs
   - Composite Convex Trap Reservoirs
   - Complex Convex Trap Reservoirs
6. Subdivision of reservoir groups into certain reservoir families differentiated by geological characteristics, for example
   - Depositional Pinch-Out Reservoirs
   - Truncated Pinch-Out Reservoirs
   - Overlap Pinch-Out Reservoirs

TABLE I

CLASSIFICATION OF PETROLEUM RESERVOIRS

	Ia APEX { DOME ANTICLINE	II STRUCTURAL SALIENT	III STRUCTURAL TERRACE	IV MONOCLINE	V SYNCLINE	VI ABSENCE OF STRUCTURE	Is PIERCEMENT SALT DOME	Id DIAPIRIC ANTICLINE	Ii IGNEOUS UPLIFT
A. CONVEX TRAP RESERVOIRS									
SIMPLE CONVEX R.	A-Ia A/Ba-Ia A/F-Ia	A-II	A-III	A-IV	A-V	A-VI	A-Is (CAPROCK)		
COMPOSITE CONVEX R.	A(F)-Ia (A+B)-Ia								
COMPLEX CONVEX R.	m(A)-Ia m(A/F)-Ia m(A/B)-Ia								
B. PERMEABILITY TRAP RESERVOIRS									
FEATHER-EDGE POROSITY R.		Ba-II Ba-II/I Ba/A-II	Ba-III Ba/A-III	Ba-IV Ba-IV/I Ba/A-IV Ba-IV/II	Ba-V Ba/A-V				
LENTICULAR R.	Bb/Ia	Bb/II	Bb/III	Bb/IV	Bb/V	Bb/VI			
FRACTURE ZONE R.	Bc-Ia								
ASPHALT-SEALED R.		Bd-II Bd-II/I		Bd-IV/I					
COMPLEX PERMEABILITY TRAP R.	m(B)-Ia								
C. PINCHOUT TRAP RESERVOIRS									
DEPOSITIONAL PINCHOUT R.		Ca-II Ca-II/I	Ca-III	Ca-IV Ca-IV/I Ca-IV/II	Ca-V		Ca-Is CaxF-Is CaxFxF-Is		
TRUNCATED PINCHOUT R.		Cb-II Cb-II/I	Cb-III	Cb-IV Cb-IV/I Cb-IV/II	Cb-V		Cb-Is CbxF-Is CbxFxF-Is		
OVERLAP PINCHOUT R.		Cc-II Cc-II/I		Cc-IV Cc-IV/I Cc-IV/II					
F. FAULT TRAP RESERVOIRS									
FAULT SEGMENT R.	F-Ia	F-II F-II/I	F-III	F-IV					
FAULT BLOCK R.	F//F-Ia								
FAULT WEDGE R.	FxF-Ia	FxF-II FxF-II/I	FxF-III	FxF-IV FxF-IV/I FxF-IV/II	FxF-V				
DOUBLE TRAP R.		FxA-II FxB-II FxC-II	FxA-III FxB-III FxC-III	FxA-IV FxB-IV FxC-IV	FxA-V FxB-V FxC-V				
TRIPLE TRAP R.				FxFxF-IV FxFxB-IV					
G. PIERCEMENT TRAP RESERVOIRS									
CRESCENT R.							Gc-Is	Gc-Id	Gc-Ii
SALT NICHE R.							Gn-Is		
PERIPHERAL WEDGE R.							GxF-Is GxB-Is	GxF-Id	
PERIPHERAL SEGMENT R.							GxFxF-Is GxFxB-Is		
COMPOSITE PIERCEMENT TRAP R.							G(F)-Is		

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 11 (NOVEMBER, 1945), PP. 1581-1592, 1 FIG.

REVIEW OF EXPLORATORY DRILLING STATISTICS 1938–1944[1]

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In August, 1937, we published in this *Bulletin* a brief review of "Wildcat Drilling in 1935 and 1936"[3] in an area of the southern states from southeastern New Mexico to Florida, inclusive. The next year two papers were published on this subject. The first[4] covered wildcat drilling in 1937 in the "southern states area" and the second[5] covered wildcat drilling in 1937 in a large number of the other states of the United States, where drilling in search of petroleum was active. These articles were, in a sense, experimental, for this study was new and the data were difficult to obtain on an analogous basis. However, by the time a statistical review was attempted for the third consecutive year,[6] the data contributed to the writer by geologists in the various districts of the country were comparable within a reasonable limit of error. Definitions were pretty clearly understood and the writer made every effort to check over the information sent to him to insure that discrepancies were reduced to a minimum. We feel confident that the figures presented annually since 1938[7] are sufficiently close to our definitions and classification to furnish a useful comparative picture of the progress of exploratory drilling from 1938 to 1944, inclusive.

We have been requested to summarize the statistics published in the several articles cited. Because of the greater coverage of the later papers, we here review only far enough back to include 1938. Furthermore, in order to make all totals correctly analogous, we omit certain states for which the data are not complete throughout this 7-year period. Not until the last 2 or 3 years have we received statistics on the northeastern states. Consequently, we omit from our totals all data for Ohio, West Virginia, Pennsylvania, and New York (Fig. 1). Also, because of the very few holes drilled in Arizona, Georgia, Iowa, North Dakota, and South Dakota, these states are omitted from this review (Fig. 1).

[1] Manuscript received, August 20, 1945.

[2] Chief geologist, Sun Oil Company.

[3] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21 (1937), pp. 1079–82.

[4] "Wildcat Drilling in 1937," *ibid.*, Vol. 22, No. 6 (June, 1938), pp. 645–48.

[5] "Further Data on Wildcat Drilling in 1937," *ibid.*, Vol. 22, No. 9 (September, 1938), pp. 1231–35.

[6] "Wildcat Drilling in 1938," *ibid.*, Vol. 23, No. 6 (June, 1939), pp. 789–94.

[7] "Wildcat Drilling in 1939," *ibid.*, Vol. 24, No. 6 (June, 1940), pp. 953–58.
"Wildcat Drilling in 1940," *ibid.*, Vol. 25, No. 6 (June, 1941), pp. 997–1003.
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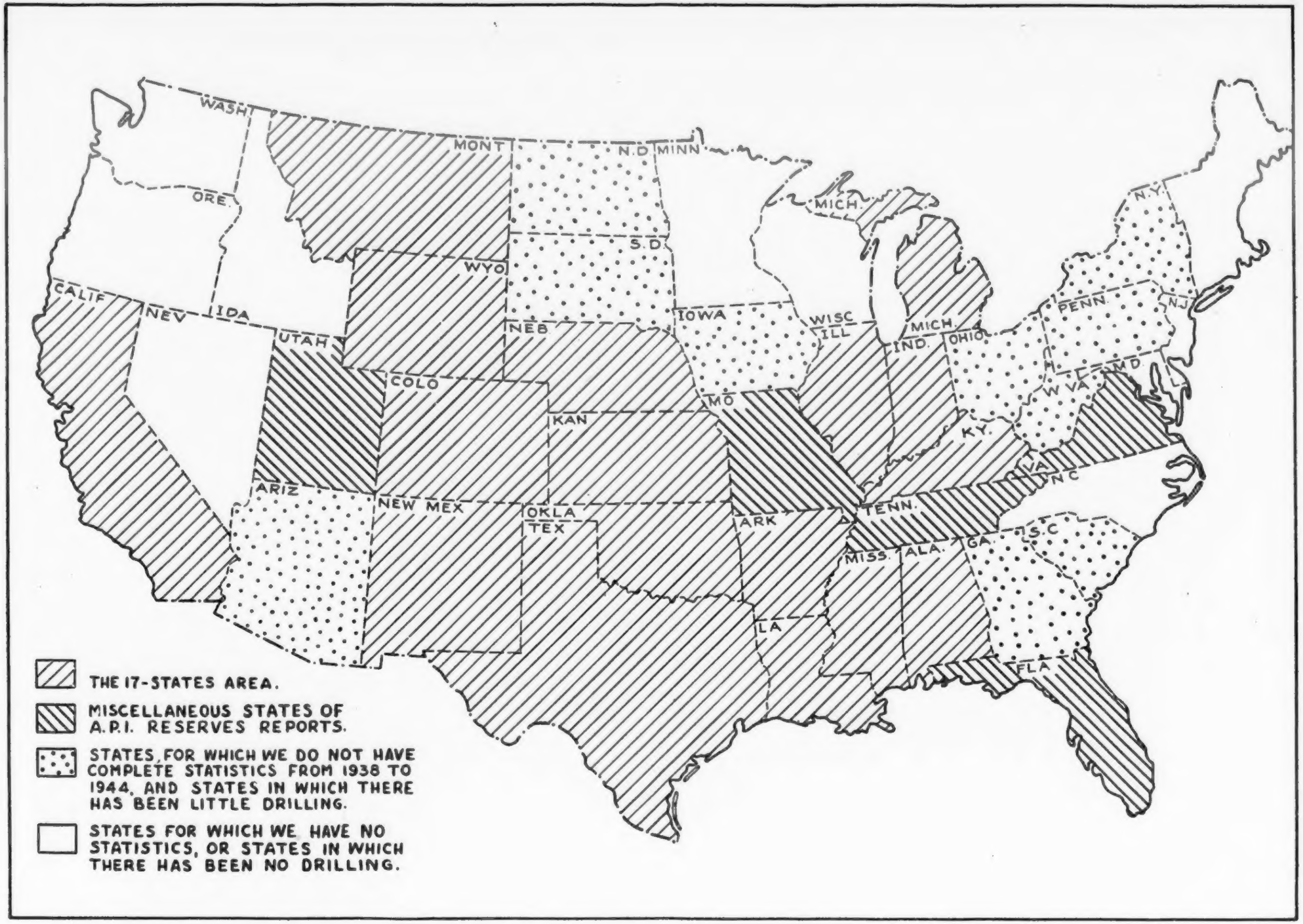
"Exploratory Drilling in 1944," *ibid.*, Vol. 29, No. 6 (June, 1945), pp. 629–45.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THE 17-STATES AREA.
MISCELLANEOUS STATES OF A.P.I. RESERVES REPORTS.
STATES, FOR WHICH WE DO NOT HAVE COMPLETE STATISTICS FROM 1938 TO 1944, AND STATES IN WHICH THERE HAS BEEN LITTLE DRILLING.
STATES FOR WHICH WE HAVE NO STATISTICS, OR STATES IN WHICH THERE HAS BEEN NO DRILLING.

FIG. 1

We may advantageously follow the grouping of states adopted by the American Petroleum Institute in its estimates of proved reserves of crude oil. Accordingly, we are calling Florida, Missouri, Tennessee, and Utah, "Miscellaneous" (Fig. 1), because their combined proved reserves are small; and we are not including the drilling in these four states in our totals.

The states which we *are* including are: Alabama, Arkansas, California, Colorado, Illinois, Indiana, Kansas, Louisiana, Michigan, Mississippi, Montana, Nebraska, New Mexico, Oklahoma, Texas, Kentucky (western), and Wyoming. These seventeen states (Fig. 1) not only include a large percentage of the exploratory drilling activities of the country, but also they contain 98 per cent of the estimated proved crude oil reserves of the United States.[8] By taking these seventeen states, for which we have full data on exploratory drilling from 1938 to 1944, and omitting those other states for which we have only partial information, we can present comparative figures of really significant value. Any details as to individual states, not herein shown, may be found in the annual articles to which reference has been made.

Briefly, then, in the summary statistics which follow, *all* totals—both for exploratory drilling and for reserves—refer to the seventeen states listed. No other states are included, and for these seventeen states the figures are complete from 1938 to 1944, inclusive. In a few instances, where data were missing in the original articles, these have now been supplied, and in two or three instances corrections of the previously published items have been made.

A review of this kind may be useful in two ways: (1) it reveals the annual changes in the figures through a period of years, and it does this much more clearly than inspection of the several detailed articles published in each of these same years; and (2) it gives us an opportunity to point out and analyze the methods and the difficulties involved in this statistical problem.

Table I summarizes the data on exploratory drilling in the seventeen states for the years 1938 to 1944, inclusive. In Column A are shown the total number of oil producers, the total number of gas (or gas-plus-condensate) producers, and the grand total of successful exploratory wells completed in the year. In Column B is given the number of new-field discoveries out of the total number of successful exploratory holes (Column A). Information for Column B was obtained in recent correspondence with contributors to statistics in the different districts of the United States, and the new-field discoveries of each year were listed. In Column C is shown the percentage of A represented by B. Apparently, since 1940 there has been a diminishing percentage of new-field discoveries.

Columns D and E are self-explanatory. In Column F, observe that the number of dry exploratory holes drilled for each successful exploratory hole has decreased since 1939. Also note, in Column I, that the number of feet drilled in dry explora-

[8] By dividing the total estimated proved reserves of these seventeen states by the total estimated proved reserves of the United States, as of December 31 of each year, from 1938 to 1944, inclusive, the same percentage of 98 is obtained. See figures published annually in the reports of the American Petroleum Institute's Committee on Crude Oil Reserves.

TABLE I

STATISTICS ON EXPLORATORY HOLES AND FOOTAGE DRILLED, AND ON AVERAGE DEPTH OF EXPLORATORY HOLE, IN 17-STATES AREA

	A	B	C	D	E	F	G	H	I	J	K
	Successful Exploratory Wells										
Year	*Total Number of Producers**	*New-Field Discovery Wells*	*B is What Per Cent of A*	*Number of Dry Exploratory Holes*	*Total Exploratory Holes (A+D)*	*Number of Dry Exploratory Holes Drilled for Each Producer (D/A)*	*Total Footage in Successful Exploratory Holes*	*Total Footage in Dry Exploratory Holes*	*Number of Feet Drilled in Dry Holes for Each Foot in Producers (H/G)*	*Total Exploratory Footage (G+H)*	*Average Depth of Exploratory Hole (J/E)*
1938	294 oil, 75 gas } 369	226	61.2	2264	2633	6.13	1,526,557	7,303,609	4.78	8,830,166	3354
1939	226 oil, 49 gas } 275	175	63.6	2396	2671	8.71	1,118,420	7,610,632	6.80	8,729,052	3268
1940	299 oil, 64 gas } 363	238	65.5	2618	2981	7.21	1,419,875	8,635,624	6.08	10,055,499	3373
1941	416 oil, 86 gas } 502	281	55.9	2716	3218	5.41	2,045,769	9,488,962	4.63	11,534,731	3584
1942	408 oil, 82 gas } 490	263	53.6	2690	3180	5.48	2,155,522	9,894,844	4.59	12,050,366	3789
1943	526 oil, 118 gas } 644	288	44.7	3144	3788	4.88	2,714,855	12,235,454	4.51	14,950,309	3947
1944	697 oil, 181 gas } 878	330	37.6	3672	4550	4.18	4,190,732	15,228,020	3.63	19,418,752	4268

* In this column "gas" includes both gas wells and gas plus condensate wells.

tory holes for each foot drilled in producer exploratory holes, has decreased since 1939. These two parallel facts suggest more success in completing producers in the more recent exploratory drilling, but mainly among the classes other than new-field ("rank") wildcats.

In Column K is an interesting record of the increasing average depth of exploratory holes from 1939 to 1944, inclusive.

Table II summarizes the statistics on the basis of locating exploratory holes. This table, like the similar detailed lists in the articles annually published by us, must be used with an appreciation of the personal equation involved in its preparation. Certainty as to all the reasons that may have entered into the final selection of a drilling site is not always possible. Blocks of acreage are sometimes taken on geological trend or on reconnaissance methods such as gravity mapping and magnetic mapping, but the actual well locations may have been designated on such blocks by more detailed work, such as core drilling or seismic exploration. Generally, both the earlier reconnaissance method and the later detail method are given credit for the well site, and they should be; but sometimes the preliminary reconnaissance method has been overlooked. For this reason there may have been some overweighting of the detail technical methods as contrasted with the reconnaissance technical methods. On the other hand, in comparing successes with failures under the several technical bases for locating wells, or under technical bases as distinguished from non-technical bases, we believe the figures are essentially analogous.

TABLE II

SUMMARY OF STATISTICS ON BASIS FOR LOCATING EXPLORATORY HOLES IN 17-STATES AREA

Year	*Geology*		*Geophysics*		*Geology and Geophysics*		*Sundry Non-Technical*		*Unknown*		*Totals*		*Grand Total*
	Prod.	*Dry*	*Prod.*	*Dry*	*Prod.*	*Dry*	*Prod.*	*Dry*	*Prod.*	*Dry*	*Prod.*	*Dry*	
1938	192	1039	78	251	31	67	44	535	24	372	369	2264	2633
1939	140	1100	69	393	13	40	43	662	10	201	275	2396	2671
1940	195	1195	100	443	22	79	35	770	11	131	363	2618	2981
1941	300	1357	143	432	28	111	29	755	2	61	502	2716	3218
1942	305	1418	110	484	42	134	22	575	11	79	490	2690	3180
1943	405	1813	147	538	65	242	21	480	6	71	644	3144	3788
1944	568	2014	145	643	102	263	58	672	5	80	878	3672	4550

In Table III are presented figures on proved crude-oil reserves for comparison with figures on exploratory drilling. The figures on reserves were taken from the published reports of the American Petroleum Institute's Committee on Crude Oil Reserves. This table is similar to those presented in our annual reviews except that, in those articles this comparative study referred to the "eleven-states area,"[9] whereas here we are considering the seventeen-states area (Fig. 1). Some explanation of the significance of Table III is desirable.

[9] The eleven states are Arkansas, California, Illinois, Indiana, Kansas, Louisiana, Michigan, Mississippi, New Mexico, Oklahoma, and Texas. To these, for the seventeen-states area, we have added Alabama, Colorado, Montana, Nebraska, Kentucky, and Wyoming.

TABLE III

SUMMARY OF STATISTICS ON PROVED RESERVES AND EXPLORATORY DRILLING IN 17-STATES AREA

Year	A	B	C	D	E	F	G	H	I
	Proved Reserves as of Jan. 1 (1000's of Bbls.)	*Proved Reserves as of Dec. 31* (1000's of Bbls.)*	*Net New Proved Reserves (1000's of Bbls.)*	*Production During Year (1000's of Bbls.)*	*Gross New Proved Reserves (C+D) (1000's of Bbls.)*	*Total Exploratory Footage (Feet)*	*New Proved Reserves (E) per Exploratory Foot Drilled (Bbls.)*	*Total Number of Exploratory Holes Drilled*	*New Proved Reserves (E) per Exploratory Hole Drilled (Bbls.)*
1938	15,102,239	17,056,370	1,954,131	1,183,733	3,137,864	8,830,166	355.3	2633	1,191,744
1939	17,056,370	18,186,767	1,130,397	1,235,013	2,365,410	8,729,052	270.9	2671	885,589
1940	18,186,767	18,688,777	502,010	1,322,794	1,824,804	10,055,499	181.5	2981	612,161
1941	18,688,777	19,270,869	582,092	1,375,411	1,957,503	11,534,731	169.7	3218	608,298
1942	19,270,869	19,792,818	521,949	1,355,102	1,877,051	12,050,366	155.7	3180	590,267
1943	19,792,818	19,759,516	−33,302	1,475,881	1,442,579	14,950,309	96.5	3788	380,828
1944	19,759,516	20,171,588	412,072	1,653,453	2,065,525	19,418,752	106.0	4550	453,961

* This figure happens to be 98 per cent of the total proved reserves of the United States as of the same date each year.

In the data published annually by the American Petroleum Institute's Committee on Crude Oil Reserves, ***new proved reserves*** are grouped under three heads, namely, (1) those resulting from revisions, (2) those resulting from extensions, and (3) those resulting from the discovery of new pools and new fields. These three classes are all included in the totals listed in Table III.

Revisions are necessary where corrections have been made in the factors involved in the estimates, for instance, in average sand thickness, in permeability, and so on. Revisions are not always upward, but, for the country as a whole, and also for the seventeen states as a group, and during the period here under special consideration, the total revision has been plus each year. Obviously "new proved reserves due to revisions" cannot be assigned directly to exploratory drilling of the *current* year. They are largely made on the basis of data secured in field development drilling. In the sense that each field, with all its reserves, is attributable to the original discovery well of the field, these revisions might be credited to the exploration program of some former year (the year of discovery).

New reserves by *extensions* are very largely proved by field development, that is, by inside drilling and by short (one or two locations) step-out drilling. Examination of a limited number of records of recent drilling programs and results indicates that possibly as low as 6 or 7 per cent of the "new proved reserves by extensions," on the average, is found by *outpost exploratory drilling*[10] in any given year, and that this may approximate 5 per cent of the total of "new proved reserves by extensions and revisions."[11] But here again, if we think of a field as the end result of discovery by a new-field wildcat, we may think of all the "new proved reserves by extensions," or at least all those proved by field development drilling, as properly creditable to this original discovery well.

In an effort to measure the degree of success of exploratory drilling, we have previously (in our published articles) divided the number of exploratory holes drilled in a given year, and the total exploratory footage drilled in a given year, into the total new proved reserves of that year, all, of course, for the same group of states. While this has given a generalized picture based on the same yardstick from year to year, it has not shown the actual quantity of new proved reserves—and observe that we are saying "new *proved* reserves"—which can be credited, in each one of these years, to the exploratory effort *of that year*. This quantity, in each year, would be much less than that which we reported, because, from the total new proved reserves we would have to subtract the new proved reserves attributable to field-development drilling. To do this requires more complete information than we have available. Nevertheless, we can arrive at a rough approximation by applying to the record of each year a few percentage factors observed in the statistics of 1943 and 1944. This has been attempted in Table V,

[10] In order that readers of this review may understand references to the classifications of exploratory holes, Table IV is here reprinted from our papers published in the Association *Bulletin* in June, 1943, and June, 1944.

[11] For purposes of illustration, we use this figure of 5 per cent. See Column I in Table V.

TABLE IV

CLASSIFICATION OF EXPLORATORY WELLS

	Classification when drilling is started	Classification after completion or abandonment: Successful	Classification after completion or abandonment: Unsuccessful
	A	B	C
Drilling for long extension of partly developed pool.	1 Outpost	1 Extension well (sometimes a new-pool discovery well)	1 Dry outpost well
Drilling for a new pool on a structure or in a geological environment already productive. — New-pool tests — Drilling within limits of area of pool. — For new pool above deepest pool.	2a Shallower-pool test	New-pool discovery wells: 2a Shallower-pool discovery well	Dry new-pool tests: 2a Dry shallower-pool test
Drilling for a new pool on a structure or in a geological environment already productive. — New-pool tests — Drilling within limits of area of pool. — For new pool below deepest pool.	2b Deeper-pool test	New-pool discovery wells: 2b Deeper-pool discovery well	Dry new-pool tests: 2b Dry deeper-pool test
Drilling for a new pool on a structure or in a geological environment already productive. — New-pool tests — Drilling outside limits of developed pools.	2c New-pool wildcat	New-pool discovery wells: 2c New-pool discovery wildcat	Dry new-pool tests: 2c Dry new-pool wildcat
Drilling for a new field (i.e., on a structure or in an environment never before productive).	3 New-field wildcat	3 New-field discovery wildcat	3 Dry new-field wildcat

TABLE V

NEW PROVED RESERVES CURRENTLY ATTRIBUTABLE TO EXPLORATORY DRILLING IN 17-STATES AREA

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Year	*Total Number of Exploratory Holes Drilled*	*16% of A (for Estimated Total Outposts)*	*41% of B (for Total Probably Successful Outposts)*	*80% of C (for Extension Outposts)*	*20% of C (Equals New-Pool Discoveries)*	*Total Successful Exploratory Holes*	*F-D Discovery Wells (New Pools and New Fields)*	*New Proved Reserves Added by Revisions and Extensions (Bbls.)*	*Assumed 5% of H Due to Exploratory Drilling (Bbls.)*	*Newly Discovered Proved Reserves (Bbls.)*	*I+J (Bbls.)*	*Total Exploratory Footage*	*K/L (Bbls.)*	*K/A (Bbls.)*
1938	2633	421	173	138.4	34.6	369	231	2,327,371,000	116,369,220	810,493,000	926,862,220	8,830,166	104.96	352,018
1939	2671	427	175	140.0	35.0	275	135	2,025,763,000	101,288,150	339,647,000	440,935,150	8,729,052	50.51	165,082
1940	2981	477	196	156.8	39.2	363	206	1,539,216,000	76,960,800	285,588,000	362,548,800	10,055,499	36.05	121,620
1941	3218	515	211	168.8	42.2	502	333	1,532,189,000	76,609,450	425,314,000	501,923,450	11,534,737	43.49	155,974
1943	3180	509	209	167.2	41.8	490	323	1,618,175,000	80,908,750	258,876,000	339,784,750	12,050,366	28.19	106,851
1943	3788	606	248	198.4	49.6	644	446	1,161,788,000	58,089,400	280,791,000	338,880,400	14,950,309	22.66	89,461
1944	4550	728	298	238.4	59.6	878	640	1,556,142,000	77,807,100	509,383,000	587,190,100	19,418,752	30.23	129,052

where we estimate that 16 per cent of all the exploratory holes[12] drilled in a year are outposts (Column B); that 41 per cent of these outposts were successful (Column C); that 80 per cent of the successful outposts were extension wells (Column D) and 20 per cent were new-pool discovery wells (Column E). These estimates, based on the assumption that the factors of 1943 and 1944 are applicable to each of the preceding 5 years, mean that the number of extension wells listed in Column D should be subtracted from the total number of successful exploratory holes (Column F) to get the number of discovery wells (new-pool discoveries plus new-field discoveries) (Column G). In Column H are shown the new proved reserves added each year by revisions and extensions. Assuming that as much as 5 per cent of these reserves of Column H are due to exploratory drilling, we have the quantities recorded in Column I. In Column J are the proved reserves added through discovery of new pools and new fields. In Column K is the total of new proved reserves attributable to the exploratory drilling of the year in which these reserves were added.

In Column L, in Table V, is shown the total exploratory footage drilled in the seventeen-states area each year; in Column M, the number of barrels of newly discovered proved reserves per foot of exploratory drilling; and in Column N, the number of barrels of newly discovered proved reserves per exploratory hole. Contrast these averages in Columns M and N of Table V with those of Columns G and I, respectively, in Table III. In Table III we used the total of new proved reserves (revisions, extensions, and discoveries), whereas in Table V we used only 5 per cent of revisions plus extensions (assumed to be that proportion directly and currently due to exploratory drilling), plus discoveries.

The reader must remember that Table V, as here prepared, is based largely on the percentage factors of the last 2 years of the period which we are discussing. Therefore, the figures may be somewhat in error, but they are certainly close enough to correctness to serve as an index of change from year to year. If this method is to be followed in the future, there will have to be careful allocation of new proved reserves to the particular classes of exploratory hole. And if the method of Table IV is used for appraising the results of exploratory drilling, we must keep clearly in mind that the figures thus presented on newly discovered proved reserves in the new pools and new fields of a given year will generally be augmented in succeeding years by "new proved reserves through extensions and revisions."

An interesting study is a comparison of the average size of fields discovered from year to year, measured in total ultimate recoverable reserves of crude oil. When a new field is opened, an estimate of its total ultimate reserves is merely a guess. As drilling progresses, and more and more becomes known of the size and shape of the structure, the thickness and extent of the producing reservoir rock, the recovery factor, how many pools are present on the structure, and what the

[12] For classification of exploratory holes referred to in later paragraphs, see Table IV.

controlling factors are on the reserves of each of these other pools—as all these things become known, better and better estimates can be made as to the total ultimate yield of the field as a whole. In general as we have observed through a study made some months ago, 1½ to 2 years of production history permit fair estimates, but obviously more time is necessary for a satisfactory appraisal of large fields or of fields with many pools at greatly varying depths.

TABLE VI

NUMBER OF FIELDS DISCOVERED EACH YEAR IN 17-STATES AREA, GROUPED ACCORDING TO ESTIMATED TOTAL ULTIMATE RESERVES

Year	Reserves Group*				
	A	B	C	D	E
	Number of Fields Discovered in Year Indicated				
1938	10	11	18	56	131
1939	6	2	11	44	112
1940	4	10	16	57	151
1941	3	6	9	66	197
1942	1	3	5	60	195
1943	1	0	8	59	221

* In these estimates of total ultimate reserves, made as of Jan. 1, 1945,
A means 50 million or more barrels
B means between 25 million and 50 million barrels
C means between 10 million and 25 million barrels
D means between 1 million and 10 million barrels
E means less than 1 million barrels.

It is our suggestion that a check, or re-appraisal, be made each year of all the field discoveries of several years, starting with the second year back and including at least the 6 or 8 preceding years. As a beginning, we have reviewed our statistics on successful exploratory holes from 1938 to 1943, inclusive, eliminating from consideration all except the new-field discoveries. This has been done with the help of our contributors to these exploration statistics in the seventeen states included in this review. Estimates of the total ultimate reserves of these fields, made as of January 1, 1945, have been credited to the year of discovery. These estimates include past production and future reserves. These estimates of total ultimate reserves are made in five categories, as follows: A, more than 50 million barrels; B, between 25 million and 50 million barrels; C, between 10 million and 25 million barrels; D, between 1 million and 10 million barrels; E, less than 1 million barrels. Table VI presents these rough estimates for the seventeen states area.

Observe that there is a decrease in the number of "A" and "B" fields, and an increase in the number of "D" and "E" fields, found each year, from 1938 to 1943, inclusive; but bear in mind that there is likely to be a shift of some of the more recently discovered "D" and "E" fields into higher reserves columns (to the left), as development extends old pools and discovers new pools not yet found

on the producing structures. Undoubtedly this will occur, but probably not enough to give a picture of major discoveries as good in the more recent years as in the earlier years of this period. An annual re-appraisal of this "picture" will be extremely interesting, and may well be carried out by our Committee on Statistics of Exploratory Drilling. In all probability this increase in the percentage of minor discoveries in recent years is in part due to the greater efficiency of exploratory methods in locating minor geological structures and to improvements in engineering and production practice whereby sands which formerly would have been overlooked or passed up are now brought into production even though the yield and the prospects are small.

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DEVELOPMENTS IN ROCKY MOUNTAIN REGION IN 1944[1]

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ABSTRACT

Drilling activities on the basis of all wells drilling in four oil- and gas-producing states of the Rocky Mountain region increased from 687 in 1943 to 916 in 1944, an increase of 33 per cent. The total footage drilled increased from 1,442,511 to 2,245,803 feet, or 56 per cent. The number of wildcat wells drilling increased from 163 in 1943 to 171 in 1944, the increase being in Wyoming. Oil production increased, except in Wyoming, which had a decline of 985,000 barrels, the first decline since 1938. New discoveries were limited, except in Wyoming, where the number of new fields and producing zones was exceptionally high, but did not contribute much new production, pending pipe-line connections and other facilities. Geologic and geophysical work also attained a new high. Increased field developments contributed much to changes in oil reserves.

INTRODUCTION

The district covered is the same as in 1943—Colorado, Montana, Utah, Wyoming, northwestern New Mexico, and parts of adjoining states. Information available regarding New Mexico is limited, but it is understood there were no discoveries or unusual developments in the Rocky Mountain part of the state. Some of the statistical information is confined for comparative purposes to the first four states.

DEVELOPMENT

Development, on the basis of wells drilling and footage drilled, was substantially greater than in 1943 or any previous year. Table I shows the wildcat

TABLE I

TOTAL DRILLING ACTIVITY IN FOUR STATES

	Colorado		*Montana*		*Utah*		*Wyoming*	
Year	*Wells*	*Footage*	*Wells*	*Footage*	*Wells*	*Footage*	*Wells*	*Footage*
1942 (A)	14	37,128	19	30,027	6	11,807	42	73,444
1943 (A)	22	43,261	73	148,398	9	22,066	59	117,468
1944 (A)	22	56,449	73	146,581	5	6,643	71	179,471
1942 (B)	55	109,125	265	464,858	6	11,807	179	483,025
1943 (B)	78	118,364	373	680,145	9	22,066	227	621,936
1944 (B)	94	246,165	497	1,030,544	9	7,535	316	961,559

Note: (A) Wildcat and semi-wildcat wells drilling and footage drilled.
(B) All wells drilling and total footage drilled during year.

TABLE II

OIL PRODUCTION IN BARRELS

State	*1942*	*1943*	*1944*	*Accumulated*
Colorado	2,287,275	2,363,335	3,075,990	49,930,506
Montana	8,063,817	7,892,205	8,623,264	114,421,305
NW. New Mexico	474,390	433,290	461,532	9,118,348
Utah*	3,849	15,159	21,557	331,681
Wyoming	32,855,795	34,230,711	33,245,333	632,771,864
Totals	43,685,126	44,934,700	45,427,676	806,573,704

* Includes distillate from Clay Basin gas field.

[1] Manuscript received, September 11, 1945. Published by permission of the director of the Geological Survey.

[2] Petroleum engineer, Geological Survey, United States Department of the Interior.

and semi-wildcat and the total drilling activity in four states in 1942, 1943, and 1944. Table II shows the oil production in barrels during those years, and the total accumulated production to the end of 1944. North Dakota and South Dakota produce only a small amount of gas, and other parts of the region are non-productive.

Colorado.—Thirty oil wells were completed, as compared with 16 in 1943. Five of these were in the new Clark Lake field, 1 was an extension well in the old Fort Collins field, 5 were at North McCallum, 1 at Powder Wash, 7 in the Rangely shallow Mancos zone, 3 in the Rangely deep or Weber pool, and 8 at Wilson Creek. One small gas and condensate well was completed at White River.

The increase of 713,000 barrels in oil production was due mainly to additional drilling and production at Wilson Creek, also to new production at Clark Lake, North McCallum, and Rangely. Development of the South McCallum field was postponed indefinitely after a fourth well produced only a small amount of oil with a large amount of carbon dioxide gas. In the North McCallum field, a pilot plant demonstrated that the carbon dioxide could be separated from the oil and tests showed the practicability of returning the gas to the reservoir. A combined extraction and repressuring plant was erected. Extensive production began on May 4.

Oil reserve estimates by three independent agencies and two trade journals, (American Petroleum Institute, Petroleum Administration for War sub-committee, United States Geological Survey Conservation Branch, *Oil and Gas Journal*, and *Oil Weekly*) increased the Colorado reserves between 27,141,000 and 51,647,000 barrels, with estimates of remaining reserves between 57,920,000 and 96,526,000 barrels. The average of the five estimates, 83,000,000 barrels, is nearly 100 per cent more than the average at the beginning of the year.

Montana.—About 216 oil wells were completed: 95 at Cut Bank, 93 at Kevin-Sunburst, 15 on the Montana side of the Elk Basin field, 5 at Gage, and 8 in other fields. Gas-well completions included 84 wells; 51 at Bowdoin, 21 at Cedar Creek (Baker-Glendive), 3 at Cut Bank, 5 at Kevin-Sunburst, and 4 in other fields. In 1943, 158 oil wells and 51 gas wells were drilled.

The accelerated drilling campaign resulted in an oil production of 731,000 barrels more than in 1943. Elk Basin, Cut Bank, Kevin-Sunburst, Pondera, and the new Gage field contributed to this increase. Results of drilling and production tests at Brady, Conrad-Midway, Farmington, and other areas were disappointing.

A comparison of oil reserve estimates by the same five sources mentioned under Colorado varied from one showing a loss of 10,637,000 barrels between January 1, 1944, and January 1, 1945, to one with a gain of 14,682,000 barrels during that period. The lowest estimate as of January 1, 1945, was 92,680,000 barrels; the highest 215,748,000 barrels. The average of the five gives a remaining reserve of 132,000,000 barrels, which is higher than the three most conservative estimates.

Wyoming.—Field activities and discoveries of various kinds were considerably greater than in 1943, although production declined 985,000 barrels. This was the first decline since 1938. Several of the new discoveries were made late in the year and were awaiting pipe-line connections or other facilities at the end of the year.

About 176 oil wells were completed, as compared with 102 in 1943. These included: Byron, 8; Cole Creek, 5; Elk Basin, 47; Garland, 12; Grass Creek, 5; Lance Creek, 8; Lost Soldier, 7; Maverick Springs, 5; Oregon Basin, 28; and 30 other fields, 51 wells. Seven gas wells were completed, as compared with 5 in 1943. Four of these were in old fields, and 3 were exploratory wells which were plugged back to gas sands after being unsuccessful in deeper drilling at Bell Springs, Little Grass Creek, and Powder River.

The five oil reserve estimates compared varied from one showing a loss of 17,254,000 barrels to one with a gain of 112,084,000 barrels during 1944. The lowest estimate was 482,140,000 barrels; the highest, 742,833,000 barrels. The average of the five gives a remaining reserve of 619,400,000 barrels, and a gain of 50,676,000 barrels.

NEW FIELDS DISCOVERED

For additional data regarding the fields or areas mentioned in the following sections, see Table V. Legal descriptions of wells are not given if the well is listed in that table.

Colorado.—The only new discovery was the Clark Lake field in Larimer County. The discovery well was drilled by the Amerada Petroleum Corporation to 6,510 feet in the Sundance formation in the NE. ¼, SW. ¼ Sec. 15, T. 9 N., R. 68 W., in 1943, and was plugged back and completed in the Muddy or upper Dakota sand at 5,888–5,924 feet in February, 1944. This well swabbed 202 barrels of 38° A.P.I. gravity oil the first 24 hours. It is 1,391 feet lower structurally than the lowest productive well in the old Wellington field, 2½ miles west, and is a reflection-seismograph discovery. Four more wells were completed and 78,000 barrels of oil were produced during the year.

Montana.—The Husky Refining Company discovered gas in the Kicking Horse dome, a small structure described by C. E. Erdmann in a United States Geological Survey map and *Press Notice 8178* of August, 1942. The gas showings were not proved important until the well was completed, August 20, in the top of the Madison limestone at 2,040 feet, with an estimated volume of 20,000,000 cubic feet of gas and 580 pounds shut-in pressure. One additional gas well and a dry hole were drilled in the field.

The Clark Fork structure was drilled by Northern Ordnance, Inc., in 1943, to 4,300 feet, and the well was abandoned, partly because the indefinite markers in the Montana group indicated that the objective sands were considerably deeper than had been expected from available maps. The well was deepened by the General Petroleum Corporation in 1944, and found spotted saturation in the

second Frontier sandstone at 6,450–6,525 feet. Soon after being swabbed down, the well flowed 137 barrels of 45° A.P.I. gravity oil, but after several months testing in 1945, it was shut in after the production declined to 15 barrels of oil per day and 90 per cent water. The leases were returned to Julius C. Peters, Jr., the preceding owner.

A reported discovery at Farmington in Teton County is disregarded because the discovery well and four others were abandoned. Also, about 20 wells have been drilled in the Conrad-Midway area in the past 3 years, of which four were completed as oil wells, but it is not feasible to operate them for the few barrels per day they produce, and operations were suspended in the spring of 1945.

Wyoming.—New fields in Wyoming and some data regarding them are given in Table III.

TABLE III

NEW FIELDS IN WYOMING

Field	*Type of Structure*	*Producing Formations*	*Number of Previous Wells*	*Lowest Previous Depth (Feet) and Formation*
Bailey dome	Seismic dome	Sundance	4	3,600 Frontier
Cooper Cove	Anticline	Dakota	3	5,400, Frontier
Crooks Gap	Anticline	Lakota	6	4,725, Thermopolis
Half Moon	Faulted fold	Embar	3	4,212, Amsden
Little Buck Creek	Seismic dome	Dakota	2	4,964, Spearfish
Mush Creek	?	Newcastle	0	
South Elk Basin	Seismic dome	Frontier, Cloverly*	0	
Spence dome	Anticline	Amsden, Madison	14	1,506, Big Horn?
Wagonhound	Anticline	Embar	4	4,520, Embar
Winkleman	Anticline	Tensleep	2	970, Morrison

* Drill-stem tests of gas sands. All others are oil discoveries.

Two oil wells were completed at Cooper Cove and a dry hole was drilled 1,150 feet west of the second producer. A dry hole was drilled at Little Buck Creek 2,100 feet north of the discovery well. This field has been called a separate seismic high from East Lance Creek, although it may be within the same outside closure. The discovery well is $2\frac{1}{2}$ miles from the closest producer at the time at East Lance Creek, with an intervening dry hole. Four oil wells were completed at Winkleman. The South Elk Basin well had gas on drill-stem tests in the Frontier and Cloverly formations in 1944, and in the Morrison in 1945, but the important discovery is that of Tensleep oil in 1945. The discovery well is $2\frac{3}{4}$ miles south of the nearest producer at the time in the Elk Basin field, and has a Tensleep datum of $-2,040$ feet, while wells in the Elk Basin field have a Tensleep datum of $+630$ to $-1,170$ feet. The Spence discovery in the NW. $\frac{1}{4}$, NW. $\frac{1}{4}$ Sec. 9, T. 54 N., R. 94 W., was the result of cleaning out and acidizing an old hole which was drilled and reported a show of oil in 1925. The old showings were never considered commercial, although a small amount of oil may have been produced. Two new oil wells were drilled in the field, and about 4,000 barrels of oil produced during 1944. The other new fields had only the discovery well drilled during the year.

NEW PRODUCING ZONES, SANDS, AND FORMATIONS

Colorado.—The Frontier Refining Company well at White River in the NW. ¼, NW. ¼ Sec. 32, T. 2 N., R. 96 W., which was drilled to 7,005 feet in 1943, was plugged back to 6,684 feet and tested in 1944. Exhaustive tests of Wasatch and Mesaverde zones between 5,626 and 5,909 feet indicated that the well was capable of producing about 500,000 cubic feet of gas and a few barrels of condensate per day. It was shut in on August 3. A well drilled by The Texas Company in 1930 had gas at 5,544–5,560 feet in about the same zone, and has remained shut in.

Montana.—A deep test well at Dry Creek, drilled to 8,882 feet in the Cambrian, was plugged back to become the first producer from the field in the Morrison formation at 5,905–5,945 feet. No commercial showings were found below the Morrison. The initial production was 300 barrels of 53° A.P.I. gravity oil per day, but the extent of the pool is unknown. The field has produced gas from the Frontier formation since 1929, and oil and some gas from the Cloverly formation since 1930.

TABLE IV

NEW PRODUCING ZONES

Field	*Type of Structure*	*New Producing Zone*	*Previous Producing Zones*	*Year of First Discovery*
Bell Springs	Small dome	Sundance (G)	Cloverly (G)	1924 (Abd.)
Big Sand Draw	Asymmetrical anticline	Embar (G)* Tensleep	Frontier to Morrison (G)	1918
Golden Eagle	Symmetrical dome	Frontier (G)* Muddy (G) (O)	Mesaverde (G)	1921
Kirby Creek	Asymmetrical anticline	Embar	Frontier	1918
Lance Creek	Asymmetrical anticline	Morrison	Dakota to Minnelusa	1918
Little Buffalo Basin	Two domes	Cloverly (G)* Muddy (G)* Embar	Frontier (G)	1914
Little Grass Creek	Small dome	Muddy (G)	Frontier (G)	1917
Powder River	Small dome	Sundance (G)	Frontier (G)	1930
South Oregon Basin	Symmetrical dome	Lower Madison	Embar Tensleep, *etc.*	1927
Spindletop	Small dome	Tensleep	Sundance	1922
Steamboat Butte	Faulted anticline	Lakota, Tensleep	Nugget (Sundance)	1943

* Drill-stem tests only. (G) indicate gas. Others are oil.

A new producing formation was found in the Thorpe pool north of the Kevin-Sunburst field when a well in the SW. ¼, SW. ¼ Sec. 36, T. 37 N., R. 3 W., was completed in the Sunburst sand at 1,847–1,859 feet with an initial production of 280 barrels of 39° A.P.I. gravity oil by swabbing. Previous wells, drilled in 1941 and 1943, produce from a stray sand in the Ellis formation.

A well in the Flat Coulee field from which oil was reported in the Madison limestone in June, was plugged back and recompleted in the Sunburst sand, from which it was thought the oil had drained due to a faulty cement job. Two wells

drilled to the Madison in the southern part of the Cut Bank field were failures, bringing to 10 the number of such tests in widely scattered locations of the field, all of which drilled into sulphur water.

Wyoming.—Eleven new producing zones found during the drilling of deeper test wells are listed in Table IV. Some were lower zones than previously drilled, and some were intermediate zones in unsuccessful deeper tests.

The Bell Springs field had not produced previously, although a well drilled in 1924 reported several million cubic feet of gas at 1,920–1,976 feet in the Cloverly formation, and about 14 wells had been drilled in the area. The 1944 well was not successful in other formations down to the Tensleep sandstone, but was completed as a 4,000,000 cubic-foot gas well with 1,100 pounds shut-in pressure. The Golden Eagle field had been abandoned about 20 years, and the Powder River field had not been produced commercially.

The most important discovery was at Big Sand Draw. The deep well was completed in December with an initial production of 1,101 barrels of 34.8° A.P.I. gravity oil from the Tensleep sandstone at 7,281–7,593 feet. The well which discovered the Tensleep pool at Steamboat Butte was only 2,900 feet north and west from the Nugget (Sundance) discovery well of 1942, and about 115 feet lower structurally. It was dry in the Nugget sandstone and was continued as an exploratory well. Initial production, pumping, was 577 barrels of 27.7° A.P.I. gravity oil per day.

EXTENSIONS

The distinction of field extensions in the Rocky Mountain region is somewhat dependent on the methods of estimating productive areas and reserves Some reserve estimates have heretofore been discussed under "Development." The most conservative estimates are based on nominal tracts, probably of 40 acres, definitely proved by at least one productive well thereon. Spacing limitations of the Petroleum Administration for War have predicated 40-acre spacing, unless exceptions were granted. In the case of gas wells, 640-acre drilling units have been required, instead of 40-acre units. Drilling of gas wells, however, has been very limited, except in the Bowdoin and Cedar Creek fields, in Montana. Under this arrangement, extensions and revisions of productive areas and reserves may be of primary importance in new contributions.

Other estimates of productive areas and reserves of new or incompletely developed fields or pools may be based on available geologic and other technical information, such as the amount of closure deemed to be productive by available structure-contour maps and comparison with similar fields, the thickness and water-free saturation of the producing zone, porosity, permeability, and other conditions. Under unit agreements supervised by the United States Department of the Interior through the Geological Survey, productive or participating areas are dependent on agreement with the unit operator as to the lands regarded as reasonably proved to be productive of oil or gas in paying quantities. Such esti-

mates are maintained on a conservative basis and require occasional revision until the pool or field is well developed, but are not confined to a proved tract basis. An extension is a matter of regular development, unless the extension well is a semi-wildcat or wildcat well as used in this paper, which is about the same as an exploratory well under the classification of Lahee.[3]

Some of the most important extensions may be mentioned briefly.

Colorado.—At the beginning of 1944, the North McCallum field had two oil-carbon dioxide wells and an originally estimated productive area of 900 acres. Five wells were completed during the year, increasing the productive area to 1,400 acres.

The Rangely field had only one deep Weber quartzite well, the discovery well of 1933, which was shut in most of the time until 1943. This discovery well is high on the structure, with a Weber datum of -234 feet. It drilled about 600 feet of water-free formation with an effective saturation of 150 to 200 feet between 5,705 and 6,298 feet, and had the total depth of 7,173 feet. Three deep wells were completed in 1944: one was $\frac{1}{4}$ mile west of the discovery well, one a mile east-southeast and still near the axis at nearly the same elevation; and one was $1\frac{3}{4}$ miles northwest with a Weber datum of -560 feet. The field was becoming the most active in the region at the end of the year. If the wells drilled are considered to prove all the area within reasonable limits of this large structure, instead of a few proved tracts, the pool may become one of the largest in the region and one of the most prolific in oil reserves per acre in the formation drilled. This would make it exceeded in areal extent only by Cut Bank, Kevin-Sunburst, and Salt Creek.

The Fort Collins field was apparently extended $\frac{3}{4}$ mile north of the old production by the Fred Goodstein or Trigood Oil Company well, although no intervening wells were drilled. Possible extensions at Powder Wash and Wilson Creek were within conservative productive limits.

Montana.—The Texas Company completed a gas well in the Madison limestone at East Utopia, with an estimated production of 5,000,000 cubic feet of gas at 1,025 pounds shut-in pressure about $1\frac{1}{4}$ miles east of a small oil well of 1943. This company also completed an outpost oil well in the Willshaw area about 2 miles northeast of production in the Kevin-Sunburst field. This well was in Sec. 20, T. 36 N., R. 1 W., and a well in Sec. 19 was dry.

Prevol and Shay completed two oil wells in the SW. $\frac{1}{4}$, SW. $\frac{1}{4}$ Sec. 10, T. 35 N., R. 3 W., and Pacific Western Oil Corporation followed with successful wells in the SE. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 4 and the SW. $\frac{1}{4}$, NW. $\frac{1}{4}$ Sec. 9. These wells opened about 2 miles of territory northwest of previous production in the Kevin-Sunburst field, but they have been considered as outward development wells.

Wyoming.—Most of the extension wells in Wyoming are considered as development wells, and are not shown in Table V. For instance, 25 oil wells had

[3] Frederic H. Lahee, "Classification of Exploratory Drilling and Statistics for 1943," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 6 (June, 1944), pp. 701–21.

been completed in the Tensleep pool of the Elk Basin field in Wyoming and Montana in 1943, furnishing considerable information as to the extent of the pool, although 62 wells were completed in 1944, more definitely proving the pool and extending it about one mile northwest and one mile south. The only dry hole drilled to the end of 1944 was the 1943 Garth well of the Stanolind Oil and Gas Company in the NE. ¼, NE. ¼ Sec. 26, T. 58 N., R. 100 W. South Elk Basin is considered as a separate field at present.

The discovery of an extensive Tensleep oil ring in the Garland field was one of the outstanding developments of the year, and might be considered either an extension or a new producing zone. Previous to 1944, this field had only one Tensleep well at the northwest end and 1¼ miles outside of the main Madison oil pool. This old well was first completed in 1929 by the Kinney-Coastal Oil Company, and was deepened, plugged back, and produced very intermittently during the ensuing 15 years, but it did not encourage further drilling until exploratory competition and the black oil market increased. The Madison pool has an Embar-Tensleep gas-cap, the wells produce considerable water, and edge drilling was considered hazardous.

The General Petroleum Corporation completed its Howell well No. 1 in Lot 63-B, T. 56 N., R. 97 W., in February 1944, on the southerly flank of the structure 3½ miles southeast of the Kinney-Coastal well. Although it was only 3,100 feet from the nearest Madison producer, the Tensleep datum was about 850 feet lower, and was 190 feet lower than that of the Kinney-Coastal well. Several other wells were completed at both ends of the structure. The oil ring is about ¼ mile wide on the southerly flank, and wider on the northwest and southeast plunges. The steeper northerly flank has hardly been drilled. The Madison pool comprises about 2,000 acres, and the Tensleep oil ring about 1,700 acres, which surrounds a gas-cap area exceeding the Madison pool in size.

IMPORTANT WILDCATS

Table I shows the number of wildcat and semi-wildcat wells drilling and the footage drilled in 1942, 1943, and 1944 in four states. The activity, on the basis of that table, was about the same as in 1943 in Colorado and Montana, less in Utah, and greater in Wyoming.

Table V lists by township and range 136 wildcat and semi-wildcat wells more than 1,500 feet deep in six states, with data regarding them. Arizona and northwestern New Mexico are omitted for lack of detailed information, and North Dakota was inactive.

It perhaps should be emphasized that statistics compiled by the writer for a number of years, both for wildcats and other drilling, are not based on yearly starts or completions, but include all wells starting, continuing, deepening, or completing during the year. This method closely reflects the total number of wells drilling at any time during the year and the total footage drilled, but the data can not be compated with that compiled on some other basis. Many wells are

TABLE V

WILDCAT AND SEMI-WILDCAT WELLS DRILLED BELOW 1,500 FEET IN 1944

Field or Area	County	Location	Operator	Farm	1944 Footage	Total Depth 12-31-44	Status 12-31-44	Basis for Test	Producing Formation and Remarks	Deepest Drilled Formation
COLORADO										
Hardin	Weld	SE SE 20-5N-63W	Ohio Oil	Nordloh	7,985	7,985	Abd.	Seismograph		Lykins
Axial Basin	Moffat	SW NE 24-5N-94W	W. L. Karr	Karr-Greer	22	2,317	Susp.	Surface		Dakota (?)
Bell Rock	Moffat	SE SE 4-6N-92W	Stanolind	Hanawalt	9,084	9,084	Abd.	Surface	(Abd. gas in 1931)	Sundance (DT)
Cross Mountain	Moffat	SW SE 31-6N-97W	Horton & Spengler	Fee	837	1,507	Susp.	Non-tech.		Pennsylvanian
North Ft. Collins	Larimer	SE NE 18-8N-68W	Trigood Oil	Community	4,759	4,759	Oil	Seismograph	"Muddy" 4,733–50 Ex.	Upper Dakota
North Wellington	Larimer	SW SW 32-11N-68W	Amerada Pet.	Rohrbacher	6,960	6,960	Abd.	Seismograph		Lower Dakota
Haymower	Moffat	NW NW 30-12N-101W	Pacific-Western	Rowlette	3,350	3,350	Drlg.	Surface	(Abd. 4,030 ft. in 1945)	Post-Laramie
Webster Hill	Garfield	NW SE 22-6S-94W	Wasatch Oil	Clough	1,695	3,700	Abd.			Wasatch
Kit Carson	Cheyenne	SW NE 24-13S-49W	O. E. Torrey	Ruff	1,861	4,861	Abd.	Sub. & Geol.		Marmaton
Haswell	Kiowa	SW SW 2-18S-51W	Colo. Wildcat Oil	Clark	805	1,810	Susp.			
Alamo-St. Mary	Huerfano	NE SW 3-27S-67W	S. W. Pressey	Fee	250	1,500	Abd.			
Alamo-St. Mary	Huerfano	NE SW 3-27S-67W	S. W. Pressey	Fee	1,810	1,830	Susp.			
Garcia	Las Animas	SE NW 32-33S-62W	Barney Oil Corp.	Fee	400	2,250	Susp.	Surface		
	Archuletta	SW NE 18-33N-1E	L. R. Travis	Davis	2,225	2,225	Abd.	Non-tech.		Dakota
Red Mesa	La Plata	SW NE 34-33N-12W	Ashback & Locke	Kroeger	2,930	2,930	Abd.	Surface		
	Archuleta	NW NW 35-36N-1W	L. R. Travis	Fieselman	2,038	2,038	Abd.	Non-tech.		Dakota
McElmo	Montezuma	SW NW 24-36N-18W	Stanolind	Schmidt	7,046	7,046	Abd.	Surface		Elbert
Total, including 5 shallow wells not listed above—22 wells—					56,449	68,544				
Note: Clark Lake and White River also are 1944 completions, although all footage was made in 1943.										
MONTANA										
Broadview	Yellowstone	SE NW 18-3N-23E	Broadview Pet.	Stoltenberg	147	5,385	Abd.	Surface		Madison
Crooked Creek	Yellowstone	SW SE 15-4N-26E	Carter Oil	N. Pacific	6,590	6,590	Abd.	Surface		Madison
Custer	Yellowstone	SW SW 2-6N-32E	Carter Oil	State	8,614	8,614	Abd.	Surf. & Seismo.		Cambrian
Harlo	Wheatland	NW NE 13-7N-18E	Monoco Oil	Young	1,773	5,001	Susp.	Surface	(Abd. 5,930 ft. in 1945)	Devonian?
Gage	Musselshell	SE NE 14-9N-26E	Northern Ordnance	Darr	814	6,125	Oil	Extension	Amsden 6,087–6,125	Amsden
Gage	Musselshell	NE SW 19-9N-27E	Northern Ordnance	N. Pacific	1,933	6,243	Susp.	Extension		Amsden
Ingomar	Rosebud	NW SE 27-9N-35E	Northern Ordnance	N. Pacific	4,070	5,910	Abd.	Extension		Madison
Button Butte	Fergus	SE SW 20-14N-24E	R. C. Tarrant	Woodworth	287	3,312	Susp.	Surface		Madison
Dutton	Teton	SE SE 31-24N-1E	R. C. Tarrant	Hodges	1,575	1,575	Susp.	Subsurface		Kootenai
Ashmoor Block	Choteau	SW SW 22-27N-3E	Texas Co.	Shepherd	2,069	2,069	Abd.	Seismograph		Madison
Conrad-Midway	Pondera	SE NE 28-28N-1E	Hendrickson	Bratsberg	1,095	1,095	Drlg.	Extension		
Marias	Liberty	SE SW 26-29N-6E	Texas Co.	State	2,573	2,573	Abd.	Seismograph		Madison
Chester	Liberty	SE SW 21-31N-5E	Prairie Rose	Thieltges	365	1,775	Susp.			Colorado
West Utopia	Toole	SW NE 21-33N-3E	Texas Co.	Hanson	2,110	2,110	Abd.	Subsurface		Madison
East Utopia	Liberty	SW SW 14-33N-4E	Texas Co.	Laas	2,610	2,610	Gas	Seismograph	Madison 2,346–48 Ex.	Madison
Hingham	Hill	SE NW 25-33N-10E	Hingham-Hobson	Flink	654	4,018	Susp.			Madison
Prescott Block	Liberty	SE SE 19-34N-6E	Texas Co.	Raabe	3,200	3,200	Abd.	Seismograph		Madison
East Van	Toole	SE NW 9-35N-1E	Texas Co.	Hurley	2,123	2,123	Abd.	Stratigraphic		Madison
Kicking Horse	Toole	SW SE 8-36N-1E	Husky Ref.	Rankin	2,040	2,040	Gas	Surface	Madison 2,040 NF	Madison
Berthelote	Toole	SW NE 36-36N-1E	Hardrock Oil	State	2,313	2,313	Drlg.	Surface	Deep test	Ellis
Keith Block (Bear's Den)	Liberty	NW SW 29-36N-6E	Texas Co.	Cicon	3,221	3,221	Gas	Seismic	Ellis, 2,890-2,910, Ex.	Madison
Whitlash	Liberty	SW NE 22-37N-4E	Union Oil	Mahoney	4,068	4,068	Susp.	Surface	Deep test	Cambrian
Flat Coulee	Liberty	NE SW 10-37N-5E	Northern Pet.	Fee	107	3,132	Oil	Surface	PB Kootenai 2,880	Madison (DT)
Sage Creek	Liberty	NE NW 22-37N-7E	Smith et al.	Fee	315	4,103	Susp.			Ellis (?)
Cordova	Teton	NE NW 4-23N-2W	Union Oil	Asmus	1,757	1,757	Abd.	Subsurface		Madison
Collins	Teton	SW SE 11-25N-2W	Union Oil	England	1,644	1,644	Abd.	Subsurface		Madison
Farmington	Teton	SW SW 27-25N-3W	Union Oil	State	1,600	1,600	Abd.	Subsurface		Madison

TABLE V—*continued*

Field or Area	County	Location	Operator	Farm	1944 Footage	Total Depth 12-31-44	Status 12-31-44	Basis for Test	Producing Formation and Remarks	Deepest Drilled Formation
MONTANA (Cont.)										
Farmington	Teton	SW SW 28-25N-3W	Union Oil	Greene	1,746	1,746	Abd.	Subsurface	Showing in Madison	Madison
Farmington	Teton	SW SE 29-25N-3W	Union Oil	Carlson	1,769	1,769	Abd.	Subsurface		Ellis
Farmington	Teton	NE SW 11-25N-4W	Texas Co.	Burke	1,895	1,895	Abd.	Stratigraphic		Madison
Farmington	Teton	NW SE 16-25N-4W	Texas Co.	State	11	1,926	Abd.	Stratigraphic	Showing in Madison	Madison
Agawan	Teton	SW NW 1-26N-5W	Taylor & Jarvis	Cooke	2,620	2,620	Abd.			Madison
Conrad-Midway	Pondera	NW NW 2-27N-1W	R. C. Tarrant	Berland	1,520	1,590	Abd.	Non-tech.		Kootenai
Conrad-Midway	Pondera	SW NE 6-27N-1W	Tarrant-Crumley	Sutton	1,620	1,620	Abd.			Ellis
Conrad-Midway	Pondera	NE NW 2-27N-2W	Tarrant-Wiley	Edwards	1,715	1,715	Abd.		Showing gas in Colorado	Ellis
Brady	Pondera	NW SE 17-27N-2W	Texas Co.	Jesser	1,850	1,850	Abd.	Stratigraphic		Madison
Pondera	Teton	NE SW 23-27N-4W	A. B. Cobb	Hirshberg	1,519	5,234	Abd.	Surface & Sub.	Deep test	Pre-Cambrian
Pendroy	Teton	SW NW 8-27N-5W	Taylor & Jarvis	Read	2,860	2,860	Susp.	Non-tech.		Madison
West Pondera	Teton	SE NE 12-27N-5W	Texas Co.	Price	2,173	2,173	Abd.	Sub. & Strat.		Madison
Pendroy	Teton	NE SE 31-27N-5W	Texas Co.	Rowland	2,438	2,438	Abd.	Stratigraphic		Madison
West Pendroy	Teton	NW NW 21-27N-6W	R. G. Anderson	Hanson	3,537	3,537	Abd.			Madison
Conrad-Midway	Pondera	SE SW 18-28N-1W	Hageman & Pond	Speer	1,720	1,720	Abd.	Extension		Ellis
Conrad-Midway	Pondera	NE NW 32-28N-1W	R. C. Tarrant	Wood	25	3,695	Susp.	Deep test		Jefferson
Sterrenberg	Pondera	NE SW 8-28N-2W	Texas Co.	Hovde	2,044	2,044	Abd.	Stratigraphic		Madison
Pondera	Pondera	SE SE 14-28-4W	Carter Oil	Warwick	2,657	2,657	Abd.			Madison
Conrad Butte	Pondera	SE NW 12-29N-1W	R. C. Tarrant	McCracken	1,401	2,236	Abd.			Madison
Ledger	Pondera	SW SW 35-29N-2W	Hageman & Pond	Foltz	2,057	2,057	Abd.			Madison
South Cut Bank	Pondera	SE NW 3-31N-6W	Hannah-Porter	Marceau	3,284	3,284	Abd.	Non-tech.		Madison
Hagan	Pondera	SE NE 9-31N-7W	Hagan Structure Oil	Anderson	1,330	2,180	Abd.	Non-tech.		Colorado
Meriweather	Glacier	NE SE 17-33N-9W	A. B. Cobb	Tribal	6,108	6,108	Abd.	Surface		Madison
Willshaw	Toole	NW NW 19-36N-1W	Texas Co.	Mars	1,950	1,950	Abd.	Stratigraphic		Madison
Willshaw	Toole	SW NE 20-36N-1W	Texas Co.	Wagner	2,006	2,006	Oil	Stratigraphic	Sunburst 1,737–78 Ex.	Madison
Sunburst	Toole	NW SE 6-36N-2W	Dakota-Mont.	Currans	240	1,990	Abd.	Extension		Madison
Sunburst Block	Toole	NE SE 19-36N-2W	Texas Co.	Goeddertz	1,898	1,898	Abd.	Stratigraphic		Madison
Toluca	Big Horn	NE SE 16-1S-31E	Dr. Crosby	Fee	10	2,310	Abd.			Cloverly
Toluca	Big Horn	NE SE 16-1S-31E	Dr. Crosby	Fee	2,510	2,510	Susp.			Morrison
McLeod	Sweetgrass	NW NE 16-2S-13E	Stanolind	Rostad	2,992	2,992	Abd.	Surface		Amsden
Mifflin	Yellowstone	SW NW 17-2S-29E	Carter Oil	Tribal	4,284	4,284	Abd.	Surface		Madison
Roscoe	Carbon	Lot 3– 4-6S-18E	R. C. Tarrant	MacKay	165	4,165	Abd.	Surface		Madison
Fox-Luther	Carbon	SW NE 14-6S-19E	Carter Oil	Bowlen	7,691	7,691	Drlg.	Surface	(Abd. 8,921 ft in 1945)	Morrison (1945)
Dry Creek	Carbon	NE SW 3-7S-21E	Ohio Oil	N. Pacific	7,752	8,882	Oil	Surf. & Sub.	Morrison 5,905–45 NP	Cambrian (DT)
Clark Fork	Carbon	NW NW 25-9S-22E	General Petroleum	McClellan	2,231	6,531	Oil	Surf. & Seis.	Frontier 6,463–6,531 NF	Frontier
Total, including 11 shallow wells not listed above—73 wells—					146,581	209,078				
NEVADA										
Arden	Clark	NW SE 20-22S-60E	Red Star Oil	Nelson	3,202	3,202	Susp.	Surface		
SOUTH DAKOTA										
—	Stanley	NW NW 36-5N-27E	Phillips Pet.	State	2,650	2,650?	Abd.	Core test		Sioux Qtz.
—	Stanley	NE SE 26-5N-28E	Phillips Pet.	Lang	2,457	2,457?	Abd.	Core test		Sioux Qtz.
Gustave	Harding	SE SE 32-15N-2E	Northern Ordnance	Bassett	7,038	7,038	Abd.	Surf. & Seis.		Deadwood
Ardmore	Fall River	SW SW 4-12S-4E	Woodward Oil	Schmidt	321	1,315	Drlg.	Surface	Gas showing (Graneros)	Fall River
Total, including 2 shallow wells not listed above—6 wells—					14,591	15,585				
UTAH										
Coalville	Summit	SW SE 35-3N-5E	Longwall Pet.	Union Pacific	51	4,423	Abd.	Surface		Frontier?
Cisco Dome	Grand	SE NE 23-20S-21E	Continental	Union Oil	4,744	4,744	Abd.	Surf. & Strat.	Basal sediments Moenkopi	Granite
Cane Creek	Grand	SW SW 31-26S-21E	Cane Creek Oil	Shafer	210	3,470	Drlg.	Surface		Paradox
Total, including 2 shallow wells not listed above—5 wells—					6,643	14,750				

Wyoming											
Alkali Creek	Sweetwater	SE SW	18-13N-99W	Mountain Fuel Supply	Butterwick	3,374	3,374	Drlg.	Surface	(Abd. 1945, at 3,574 ft.)	Post-Laramie
Sulphur Creek	Uinta	SW SW	13-13N-119W	Oregon Oil Co.	U. Pacific	620	2,025	Susp.			
Stove Creek	Uinta	SW NE	26-14N-119W	Production Oil	Wooton	577	2,987	Susp.			
Cooper Cove	Carbon	NW SW	20-18N-77W	Stanolind	Parkinson-Johnson	5,373	5,373	Oil	Surf. & Sub.	"Dakota" 4,834–4,910, NF	Jelm
Saratoga	Carbon	SE SW	30-18N-84W	John C. Arp	Seaverson	2,702	2,702	Susp.	Surface		Steele
Overland	Carbon	SW NW	30-20N-83W	Barron Kidd	Morris	3,249	3,249	Susp.	Stratigraphic	(Abd. 4,000 ft. in 1945)	Niobrara
Rock River (East)	Albany	SW SW	33-21N-76W	Wasatch Prod.	Mohmquist	3,454	3,454	Abd.	Surface		Sundance
Fossil	Lincoln	NW NW	23-21N-117W	Hatch & Harris	Harris	240	4,556	Drlg.	Non-tech.		
No Como Dome	Albany	SE NW	3-22N-77W	U-Tex. Oil	U. Pacific	1,861	1,861	Abd.	Surface		Pre-Cambrian
Bell Springs	Carbon	NE SW	6-23N-88W	Rocky Mountain Gas	Johnston	3,852	3,852	Gas	Seismograph	Sundance 2,272–2,360 NP	Tensleep (DT)
Bailey Dome	Carbon	NE NE	21-26N-89W	Sinclair	Coffman	5,234	5,234	Oil	Seismograph	Sundance 5,145–5,190 NF	Sundance
Barren Butte	Fremont	SE NW	32-27N-92W	Continental	Christiana	4,880	4,880	Abd.	Surface		Lewis
Spring Creek	Fremont	NW NW	7-28N-92W	Phillips Pet.	Hintze	4,808	4,808	Susp.	Surface	(Abd. 1945)	Mowry
Spring Creek	Fremont	NE NW	7-28N-92W	Phillips Pet.	Hintze	3,103	3,103	Susp.	Surface	(Abd. 1945, at 4,774 ft., Sundance)	Cloverly
Crooks Gap	Fremont	SW NW	18-28N-92W	Sinclair		5,315	5,315	Oil	Surf. & Seis.	"Lakota" 5,232–44 NF	Cloverly
Big Piney	Sublette	NW SE	23-29N-113W	Western Oil Ref.	Salathe-Hilton	107	1,508	Abd.	Extension		Wasatch
Spindletop	Natrona	SW SW	32-30N-81W	G. W. Jarvis		2,445	2,445	Oil	Surface	Tensleep 2,250–68 NP	Tensleep (DT)
Two Bar	Natrona	NE SW	24-31N-81W	Pacific Western	Oborne	4,047	4,047	Abd.	Surface		Madison
Indian Creek	Sublette	NE NE	14-31N-113W	H. H. Howell	Budd	2,428	2,428	Abd.	Non-tech.		Wasatch
Shawnee	Converse	NE SW	27-32N-69W	G. P. Dickey		4,849	4,849	Abd.	Non-tech.		Minnelusa
Iron Creek	Natrona	SW NW	11-32N-82W	Texas Co.		3,437	3,437	Abd.	Surface		Tensleep
Big Sand Draw	Fremont	NW NW	14-32N-95W	Sinclair		7,593	7,593	Oil	Combination	Tensleep 7,281–7,593 NP	Tensleep (DT)
South Cottonwood	Sublette	NW SW	9-32N-113W	H. H. Howell	Budd	1,621	1,621	Susp.	Non-tech.		Wasatch
Keeline	Niobrara	NW SE	18-33N-66W	Texas Co.	Henderson	2,680	2,680	Drlg.	Seismograph	(Abd. 3,251 ft. in 1945)	Deadwood
Oil Mountain	Natrona	NE SW	35-33N-82W	Texas Co.	Clark	2,515	2,515	Drlg.	Surface	Deadwood 3,416 ft. in 1945	
Cottonwood	Sublette	NW NW	28-33N-113W	H. H. Howell	O'Neil	2,587	2,587	Abd.	Non-tech.		Wasatch
Young Woman Crk.	Niobrara	SE NW	23-35N-63W	Maupin & Moore	Berggren	39	2,903	Susp.	Surface		
West Hat Creek	Niobrara	SE SE	34-35N-63W	Nat. Assc. Pet.	Whitmore	1,805	1,805	Drlg.	Surface		
No. Cole Creek	Natrona	SW NE	8-35N-77W	General Petroleum	Moore	4,932	4,932	Drlg.	Seismograph	(Abd. 4,960 ft. in 1945)	Shannon
Cow Gulch	Niobrara	NW NW	9-36N-62W	J. L. Berggren		1,557	1,557	Susp.	Surface		Minnelusa
Little Buck Crk.	Niobrara	SW NW	25-36N-64W	Continental	Wright	4,100	4,100	Oil	Seismograph	"Dakota" 3,808–76 NF	Lakota
Powder River	Natrona	SE SE	23-36N-85W	Stanolind	LaFleiche	4,889	4,889	Gas	Surface	Sundance 2,489–2,533 NP	Madison (DT)
Poison Creek	Fremont	NE SW	16-37N-93W	Stanolind	State	4,182	4,182	Abd.	Surface		Lewis
McComb (Lysite)	Fremont	NE NW	16-39N-91W	Ohio Oil	Ohio State	2,500	2,500	Abd.	Surface		Wind River
Kirby Creek	Hot Springs	NE NE	21-43N-92W	Pacific Western	Eagle OPC	4,427	4,427	Oil	Surface	Embar 3,420–93 NP	Madison (DT)
Mush Creek	Weston	NE SW	24-44N-63W	Western Oil Trust	Milhouse	15	3,867	Oil	Non-tech.	"Muddy" (Newcastle) NF	Graneros
Wagonhound	Hot Springs	NE SE	6-44N-98W	Broderick & Gordon	Christensen	2,534	4,700	Oil	Surface	Embar 4,278–4,302 NF	Tensleep
Golden Eagle	Hot Springs	NE SW	12-45N-97W	Pioneer Oil Corp.	On Time OPC 4	6,506	6,794	Oil & Gas	Surface	"Muddy" 6,720–70 NP	Thermopolis
Golden Eagle	Hot Springs	SW SE	12-45N-97W	Pioneer Oil Corp.	On Time OPC 2	7,385	7,385	Drlg.	Surface	"Lakota" oil (1945) NP	Morrison (DT)
Little Grass Crk.	Hot Springs	SW NW	11-46N-99W	Continental	Goodstein	3,732	6,632	Gas	Surface	"Muddy" 3,580–3,608 NP	Madison (DT)
Little Buffalo Basin	Park	SW NE	34-48N-100W	Stanolind		726	5,944	Abd.	Surface		Madison
Half Moon	Park	SW NW	23-51N-102W	Husky Refining	Morrison	4,265	4,265	Oil	Surface	Embar 3,426–54 NP	Madison
Horse Center	Park	NW SE	31-52N-101W	Husky Refining	Geiger	1,800	1,800	Abd.	Surface		Devonian(?)
Alkali Anticline	Big Horn	SE NE	33-55N-95W	Yale Oil	Carter	669	3,525	Abd.	Surface		Madison
So. Elk Basin	Park	SE SW	20-57N-99W	Continental	Goodstein	5,497	5,497	Drlg.	Surf. & Seis.	Gas—1944, Oil—1945 NF	Tensleep (1945)
Winkleman	Fremont	SE SW	18-2N-1W	Stanolind	Tribal	2,532	3,315	Oil	Surface	Tensleep 2,915–3,205 NF	Tensleep
Steamboat Butte	Fremont	NE SE	31-4N-1W	British-American	Tribal	1,114	7,034	Oil	Extension	Tensleep 6,772–7,034 NP	Tensleep (DT)
Little Dome	Fremont	SE SE	10-5N-1W	Superior Oil	Tribal	4,111	4,111	Abd.	Surf. & Sub.		Tensleep
Little Dome	Fremont	SE SE	10-5N-1W	Superior Oil	Tribal	4,150	4,150	Abd.	Surf. & Sub.		Chugwater
Sheldon	Fremont	NE NE	16-5N-2W	Kerlyn Oil	Tribal	5,739	5,739	Drlg.	Surf. & Seis.		
Dry Creek	Fremont	NW NW	27-6N-3W	Sinclair	Tribal	4,191	4,191	Abd.	Surf. & Seis.		Chugwater
Total, including 20 shallow wells not listed above—71 wells—						179,471	219,431				

Abbreviations Used
Ex = Extension well
NF = New field
NP = New pool in old field
DT = Deep test well
(The above shown mainly for productive pools)

Abd = Abandoned
Drlg. = Drilling
Susp. = Suspended
Surf. = Surface
Sub. = Subsurface
Seis. = Seismograph
Non-tech. = Probably non-technica

suspended for the winter or are drilling intermittently for other reasons, and it may be several years until final completion or abandonment occurs. Wells less than 1,500 feet are omitted from the wildcat list, but not from the statistics, to save time and space. These wells would appear in a later list, when they reach that depth; if they do not, their importance is questionable, except as a dry-hole record.

The wildcat and semi-wildcat wells are deemed to be exploratory wells, being a mile or more from any producer, tests of deeper formations, or out-and-out wildcats. There are very few extension wells listed, because most extensions were only a nominal distance and not unduly down-structure from previous producers. Exceptional situations may occur, however, such as at Garland, Lance Creek, and South Oregon Basin, where new zones were discovered in what might be termed development wells.

GEOPHYSICAL PROSPECTING

Geophysical prospecting in the region was at an all-time high, according to the Rocky Mountain Oil Scouts Association. Activity increased from 91 crew months of seismograph work in 1943 to 254 crew months in 1944 or 179 per cent, about two-thirds of which was in Wyoming, and most of the balance in Montana and Colorado. A comparison of 1943 and 1944 reports indicates that the number of companies sponsoring this work increased from 5 to 11 in Colorado, 3 to 9 in Montana, and 15 to 24 in Wyoming. The basis for many of the wildcat tests is indicated in Tables III and V.

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CRETACEOUS STRATIGRAPHY OF VERMILION AREA, ALBERTA, CANADA[1]

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ABSTRACT

Cretaceous sediments are penetrated in wells in the Vermilion area of east-central Alberta to depths of 2,000 to 2,500 feet; they rest unconformably either on Devonian dolomites or on a few feet of green shale possibly Jurassic in age.

Only one formation, previously unnamed, is Lower Cretaceous in age. It consists of deltaic and associated sediments which are subdivided for the first time into six local members largely on the basis of presence or absence of dark minerals in the sands, microfossils in the marine shale tongue, and occurrence of coal seams. This association of sediments is comparable with the Recent deposits of the Mississippi Delta region.

The lower part of the Upper Cretaceous consists of two rather widespread marine shale formations, together about 1,600 feet thick, the older one with white calcareous specks, the younger one without them. These formations are overlain by fresh- and brackish-water sandy sediments, which thin toward the east and are replaced by interfingering marine shales. The interfingering marine shales and near-shore deposits are exposed in the Vermilion area. Their rapid lateral variations make detailed correlations and surface geology difficult.

INTRODUCTION

The discovery of petroleum near Vermilion in 1940 stimulated an active program of wildcatting, core-drilling, and geological surveys in which much new stratigraphic information has been obtained. This new information has enabled a general revision of the Cretaceous stratigraphy. The Lower Cretaceous has been subdivided, additional foraminiferal zonation of the marine shales has been effected, and more data on the interfingering near-shore members of the Upper Cretaceous have been collected.

The Vermilion area is on the plains of east-central Alberta, Canada, 250 miles northeast of the eastern margin of the Rocky Mountains and about 200 miles southwest of the pre-Cambrian shield. It comprises approximately 5000 square miles between 52°45′ and 54° North Latitude and 110° and 112° West Longitude.

REVIEW OF PREVIOUS WORK

The Vermilion area was visited by some of the early explorers. The first to leave a record was the party under M. Legardeur de Saint-Pierre who, in 1750, ascended the North Saskatchewan River in order to find a route to the western

[1] Manuscript received, June 11, 1945. This paper is part of a thesis presented to the department of geology, Stanford University, California, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Another part, dealing with the micropaleontology of the area, is being prepared for publication.

[2] International Petroleum Company, Ltd. The writer is deeply indebted to H. G. Schenck, Stanford University, for his direction of this investigation and cordially thanks T. A. Link, Imperial Oil Company, for his supervision of the field work. Considerable information on well logs was obtained from A. J. McCaskill and Norman Soul. Stimulating discussions were had with W. Nygren, Standard Oil Company of California. Ian M. Cook gave information on well samples and G. S. Hume, Canadian Geological Survey, pointed out outcrops which added to the knowledge of the Vanesti tongue on Battle River. J. C. Sproule, Imperial Oil Limited, imparted many helpful suggestions. The aid which Myra Keen, Stanford University, has given, in preparing this article for publication, is deeply appreciated.

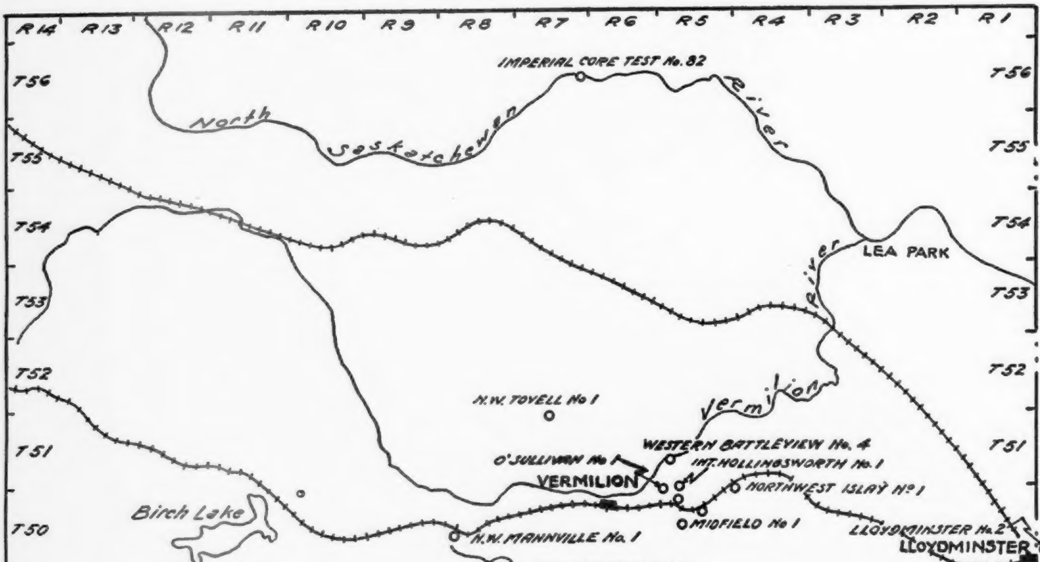


FIG. 1.—Outline map of Vermilion area, showing wells referred to in this paper.

sea. At a later date the region was traversed by other well known explorers: Fidler in 1792, Thompson in 1798–1807, D. McGillivray in 1825, Douglass in 1827, Simpson in 1841, and Richardson in 1851. The travels of these intrepid men revealed for the first time the more general aspects of the geography of this unsettled country (Tyrrell, 1887, pp. 7–11).

The first geological work was done by the expedition under Captain J. Palliser in 1857. Sir Roderick I. Murchison selected Dr. J. Hector to accompany this expedition in the combined capacity of surgeon and geologist (Hector, 1861, p. 388). Hector drafted the first geological map of the area included in what is now southern and central Alberta. Because of the reconnaissance nature of the survey, he failed to establish the order of superposition of the beds exposed on the Plains, and he correlated those beds now called Edmonton with Meek and Hayden's "Division No 1," which later became known as the Dakota group. Notwithstanding its imperfections, the most important contribution of this expedition was the first serviceable map of the Northwest.

The next work of importance was that by J. B. Tyrrell (1887). He made a relatively accurate geological map of the greater part of central Alberta, and he was the first geologist to use the name Belly River for the sands in the Vermilion area. His map had only one major misinterpretation. He believed that the Lea Park shales which crop out on the North Saskatchewan River at the Saskatchewan boundary were younger than the Belly River. This error necessitated the incorrect assumption that a major anticline trended northwest across the southern half of the Vermilion area. This structure he believed to be the northern extension of the Sweetgrass arch. Tyrrell's report contained an excellent description of the topography, a factual account of the stratigraphy, and a section on systematic paleontology by J. F. Whiteaves, in which a number of new species of Mollusca were described. Noteworthy is the fact that Tyrrell's map was not improved upon for many years; the geological map of western Canada issued in 1913 was essentially the same.

The fourth stage in the development of knowledge of the Vermilion area came in 1918 when papers by Allan and Slipper were published. In that year Allan published a geological map of the region through which the North Saskatchewan River flows from Edmonton to North Battleford (Allan, 1918). He pointed out that the anticline mapped by Tyrrell does not exist and that the Vermilion area is located on a monocline rather than an anticline. During the same year S. E. Slipper (1918) worked south of the river in the Wainwright and Viking districts. Both Slipper and Allan subdivided the Belly River and proposed for these units the names which have been in common use until the present time.

Since 1918 numerous minor reports on the stratigraphy, paleontology, and oil prospects of the Vermilion area have been written. In these, however, the stratigraphic section as established by Slipper and Allan has remained essentially unchanged.

With the discovery of oil near Wainwright in 1923, detailed exploration was

begun by G. S. Hume, of the Geological Survey of Canada, and continued intermittently to date. In 1935 and 1936 P. S. Warren and G. S. Hume mapped the southern part of the area. As a result of this and other work, the Hardisty and Ribstone sheets were published in 1939 by the Geological Survey of Canada on a scale of 1 inch = 4 miles.

Finally, Hume and Hage (1941) published a comprehensive report on the geology of east-central Alberta, in which the stratigraphic sequence and nomenclature are essentially the same as that presented by Slipper in 1918.

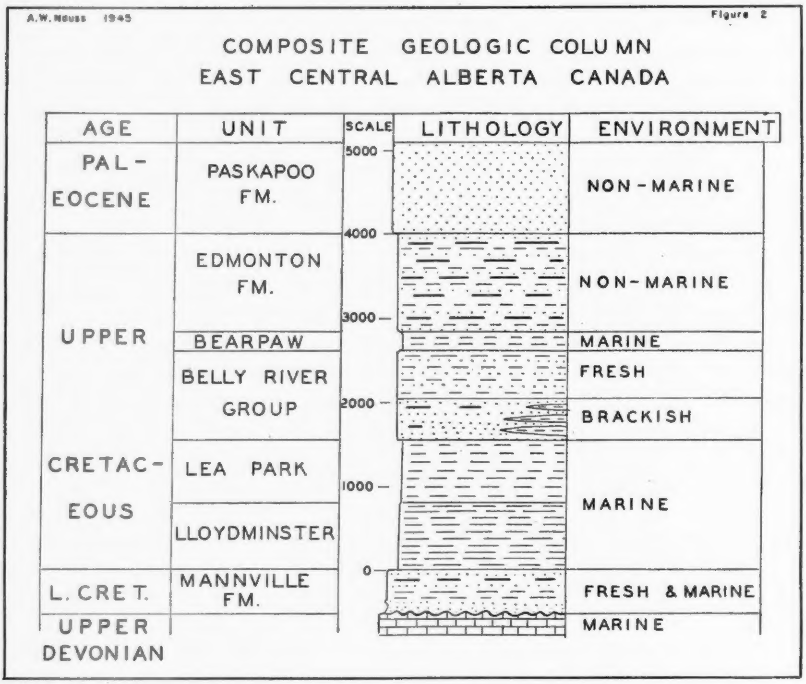


FIG. 2

STRATIGRAPHY

INTRODUCTION

Cretaceous sediments constitute the surface formations throughout the Vermilion area and are penetrated in wells to depths of 2,000 and 2,500 feet. These sediments are overlain southwest of the area by Tertiary sandstones of continental origin and are unconformably underlain by dolomitic limestone of Devonian age (Fig. 2). At some localities a few feet of green shale underlies the Cretaceous and this has been tentatively assigned to the Jurassic on the basis of

lithology. The Cretaceous succession is made up of: three formations of marine shale, two of non-marine sediments, and two units of near-shore sediments characterized by interfingering marine shales, beach sands, and coastal swamp deposits. The relationships of these near-shore sediments suggest that during several periods of Cretaceous time the Vermilion area was in the region of accumulation of deltaic and related sediments, near the mouth of a mighty river.

MANNVILLE FORMATION

Name and type locality.—The "Lower Cretaceous" beds in the Vermilion area are lithologically distinct from any known formations of similar age in western Canada. They differ from equivalent beds in the Peace River and McMurray districts in being almost entirely non-marine. Moreover, they differ from correlative beds in the Rocky Mountain district in containing near-shore quartz sands and one thin marine shale member. Finally, they do not contain the red and green shales which are characteristic of the "Lower Cretaceous" of southern Alberta. Therefore, the new name "Mannville" is proposed here for this formation in the Vermilion area. The type locality is in the Northwest Mannville well No. 1, between the depths of 1,833 and 2,308 feet.

Lithology.—The Mannville formation consists of interbedded "salt-and-pepper"[3] sands, non-marine gray shale, quartz sand, coal seams, and a marine shale member with a thickness of 0 to 90 feet. Locally one may divide the Mannville formation into six members here named as follows in order of increasing age: the O'Sullivan, Borradaile, Tovell, Islay, Cummings, and Dina members (Fig. 3). These units have been given the status of members rather than formations because of their relatively limited geographic distribution.

The type locality of each of these members is in the Northwest Mannville well No. 1 (Legal subdivision 1, Sec. 18, T. 50 N., R. 8 W., 4). Because of the paucity of geographic names in the vicinity of Mannville, the names of the members are taken from other localities in the Vermilion area where these members are well developed, but in order to avoid the possibility of future confusion the section in the Northwest Mannville well is designated herein as the type of each and all of them. The following log of the Northwest Mannville well No. 1 is based on continuous cores through the Mannville formation, on rotary-drill cuttings, and an electric log and on time-drilling logs at various depths.

NORTHWEST MANNVILLE WELL NO. 1

Location.—Legal subdivision 1 of Sec. 18, T. 50 N., R. 8 W., 4th Meridian. Stanford University locality M-314.
Elevation.—2,094 feet (rotary table). Depths in feet.
Log of samples

BIRCH LAKE SANDSTONE
0– 10 Buff sand and oyster shells.
GRIZZLY BEAR TONGUE
– 80 Gray and buff shale and sand

[3] Sands containing appreciable percentages of both light- and dark-colored minerals.

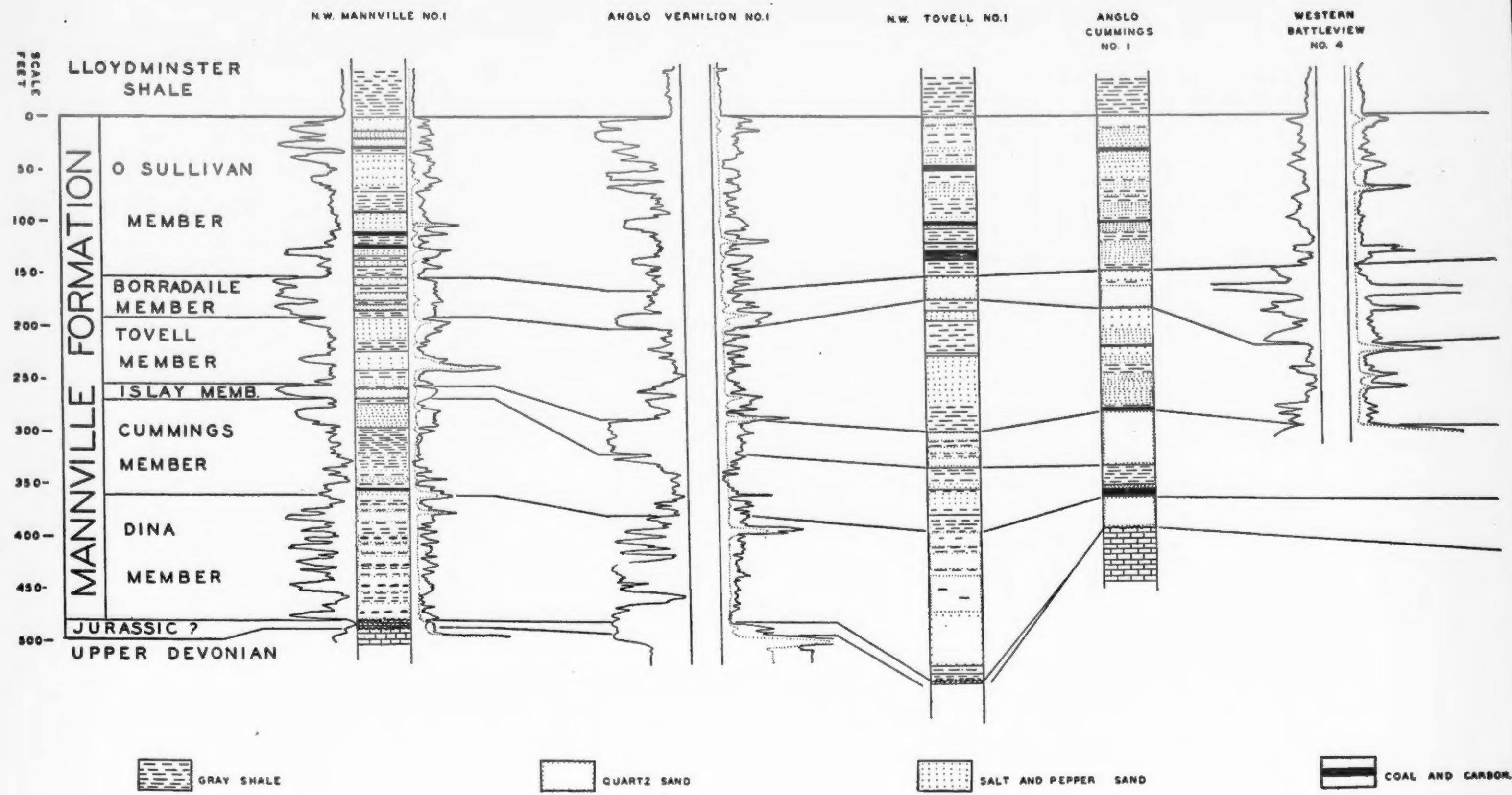
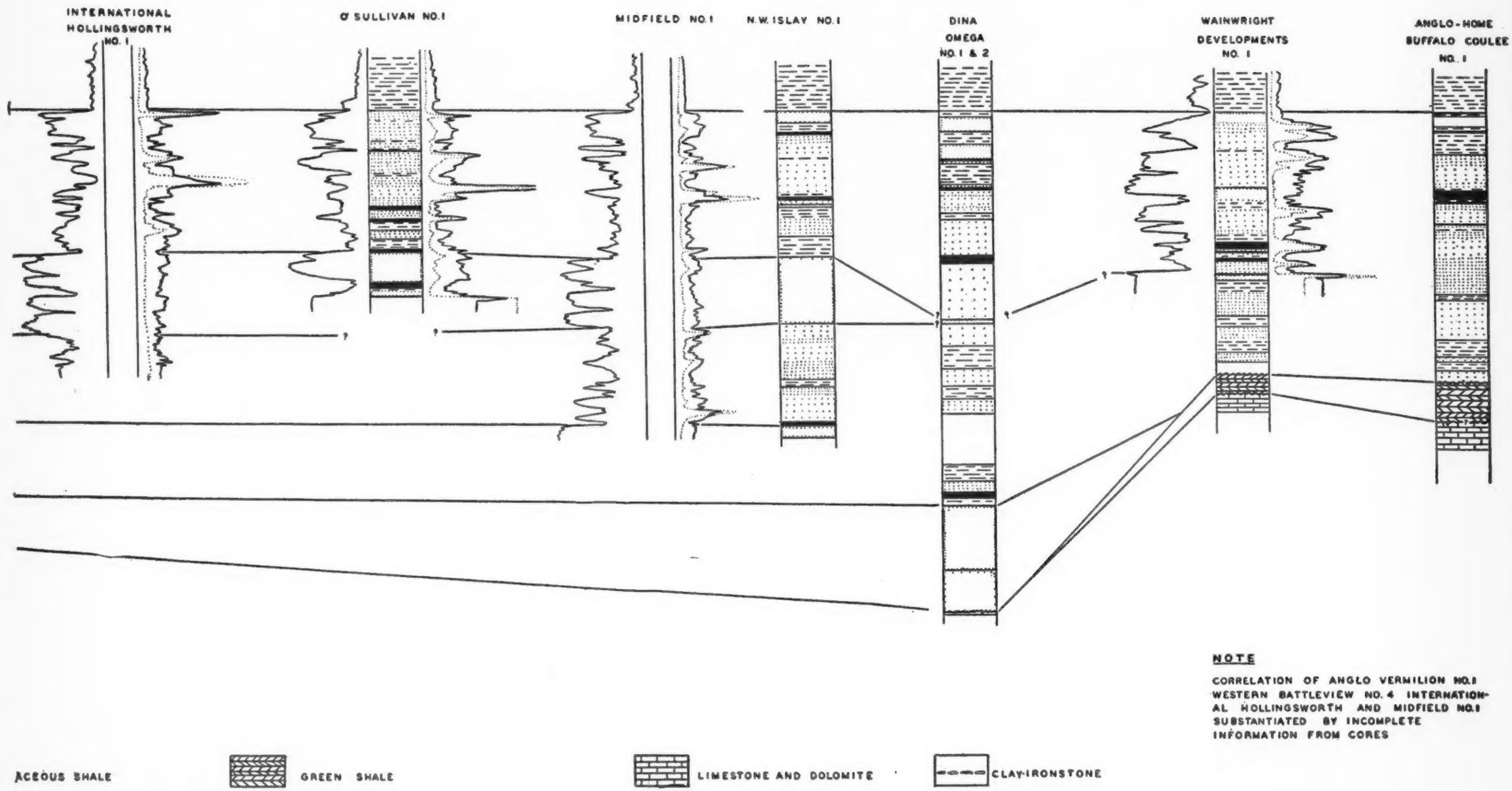


FIG. 3.—Correlation chart of



members of Mannville formation.

NORTHWEST MANNVILLE WELL NO. 1—*Continued*

UPPER RIBSTONE CREEK
- 90 Gray shale and coal
- 110 Coarse, gray sand
- 120 Gray sand, some shale

VANESTI TONGUE
- 150 Gray shale

LOWER RIBSTONE CREEK
- 190 Coarse, gray sand
- 230 Fine sand and silt
- 240 Coarse sand
- 270 Fine sand

LEA PARK SHALE
- 530 Gray shale
- 540 Gray shale, "*Verneuilina*" cf. *bearpawensis*, *Bulimina* sp.
- 730 Gray shale, "*Verneuilina*" cf. *bearpawensis*, *Anomalina* sp., *Haplophragmoides* sp., *Neobulimina canadensis* (rare)
- 890 Gray shale, *Haplophragmoides* sp., *Epistomina* sp., *Robulus* sp.
- 1050 Gray shale, *Haplophragmoides* sp., *Dentalina* sp., *Gyroidina* sp., *Dictyomitra multicostata*, *Epistomina* sp., *Anomalina* sp.

LLOYDMINSTER SHALE
- 1270 Dark gray shale, flaky, white calcareous specks, *Gümbelina globulosa*, *Ammodiscus* sp. (and mixture of all species listed above)
- 1490 Dark gray flaky shale, *Globigerina* sp., *Haplophragmoides* sp., *Globigerina cretacea*
- 1530 Dark gray flaky shale, *Globigerina* sp., *Tritaxia* sp.
- 1580 Dark gray flaky shale
- 1595 Dark gray flaky shale, *Haplophragmoides excavata*, *Miliammina manitobensis*
- 1600 Dark gray flaky shale, *Ammobaculites* sp., *Haplophragmoides* sp.
- 1750 Dark gray flaky shale
- 1760 Dark gray shale, *Verneuilina canadensis*, *Haplophragmoides* sp.
- 1808 Dark gray shale

Log of cores
- 1833 Dark gray shale, *Inoceramus* fragments, *Haplophragmoides gigas*, *H.* sp., *Gaudyrina* sp., *Verneuilina canadensis*, *Ammobaculites* sp., *A. fragmentaria*

MANNVILLE FORMATION

O'Sullivan member
- 1838 Fine-grained sandstone, dark minerals not abundant
- 1841 Friable medium-grained sandstone
- 1856 Laminated silt and gray shale, thin bed of coal
- 1859 Thinly bedded fine-grained sand, with a few gray shale partings
- 1867 Dark gray shale
- 1882 Medium- and fine-grained friable salt-and-pepper sandstone
- 1885 Laminated silt
- 1897 Massive medium-grained friable salt-and-pepper sandstone
- 1922 Laminated siltstone and gray shale, abundant plant remains
- 1923 Coal and carbonaceous shale
- 1941 Fine and coarse friable salt-and-pepper sandstone, cross-bedded, abundant carbonaceous material
- 1942 Coal
- 1954 Dark gray shale and silty shale
- 1960 Black carbonaceous shale
- 1964 Light gray fine-grained sand
- 1969 Gray shale and some silt
- 1974 Fine-grained salt-and-pepper sand
- 1988 Massive dark gray shale and argillaceous silt, no carbonaceous material

Borradaile member
- 1994 Medium-grained quartz sand, well sorted
- 2004 Buff silt and gray shale
- 2007 Hard cross-bedded brownish gray calcareous fine-grained quartz sandstone
- 2012 Gray silt and dark gray carbonaceous shale
- 2017 Massive brownish gray soft fine-grained cross-bedded sandstone, mostly quartz

Tovell member
- 2024 Interbedded gray siltstone and shale
- 2045 Medium- and coarse-grained salt-and-pepper sandstone

NORTHWEST MANNVILLE WELL NO. 1—*Continued*

–2050 Soft laminated and thinly bedded siltstone, some gray shale, abundant plant remains
–2052 Massive dark gray shale, conchoidal fracture, pyrite, basal contact sharp
–2053 Soft fine-grained gray sandstone
–2061 Thinly interbedded fine sand and soft shale
–2062 Coal and carbonaceous shale
–2072 Coarse-grained salt-and-pepper sand
–2081 Gray silt and silty shale
–2083 Medium-grained salt-and-pepper sand
–2090 Dark gray shale, *Trochammina* sp.
–2095 Light gray fine-grained soft salt-and-pepper sandstone
Islay member
–2015 Soft light gray fine-grained quartz sand some shale partings
Cummings member
–2108 Interbedded gray shale, with abundant partially pyritized plant remains, and fine sand
–2130 Light gray medium-grained friable salt-and-pepper sandstone, several lenses of shale near base
–2152 Black shale
–2182 Interbedded black shale and gray siltstone, abundant pyrite, *Miliammina* sp., *Haplophragmoides* sp., *Ammobaculites fragmentaria*
–2187 Irregularly bedded and laminated siltstone
–2188 Coal and black carbonaceous shale
–2193 Laminated siltstone and fine sandstone
Dina member
–2211 Interbedded dark gray shale and light gray silt, thin beds of fine-grained quartz sand, abundant plant remains
–2213 Light gray fine-grained quartz sand
–2306 Interbedded gray shale and light gray siltstone, some fine-grained quartz sand, argillaceous siderite nodules and layers common, plant remains
–2308 Light gray fine and medium-grained quartz sand
JURASSIC
–2313 Greenish gray calcareous shale, abundant plant leaves
DEVONIAN
–2356 Hard dense limestone
–2361 White, crystalline limestone, stylolites, some large cavities
–2428 Light gray crystalline limestone, brachiopod fragments
–2433 Light gray massive fossiliferous limestone, pyrite

The six members of the Mannville formation can not be recognized in rotary-drill cuttings, and only by close scrutiny can they be discriminated in cable-tool samples. The members are differentiated from one another by the presence or absence of dark minerals in the sands, by the rounded, frosted, and well sorted character of the quartz sands, by the microfauna of the marine Cummings member, and by the order of superposition of these lithologic units. Cores suggest that the contacts between the members are conformable.

DINA MEMBER

The Dina member consists chiefly of quartz sand having rounded grains and interbedded with silt and shale. Dark minerals are noticeably rare. The grains attain a maximum size of 1 millimeter near the base. The sand is unconsolidated and caves in drilling operations if the mud is not kept at the proper consistency. The lower limit of the member coincides with the base of the Mannville formation and its upper limit is at the highest occurrence of quartz sand.

The thickness of the Dina member is more variable than that of all the other members in the Mannville formation and ranges from 0 to 150 feet. Most of the variation in thickness of the entire Mannville formation is due to the changing

thickness of this one member. Where the top of the Paleozoic is high the Dina member is thin or absent; in the intervening depressions it reaches its maximum thickness.

The lithologic character of the Dina member is similar to that of the McMurray formation, which likewise fills the hollow between the Devonian limestone "highs" 200 miles north (Sproule, 1938, p. 1137). The quartz of the Dina member may have been derived from the underlying Devonian limestone, which contains abundant sand grains composed of that mineral. The well sorted, frosted, and rounded sand grains of the Dina member and its position above an unconformity suggest that it is a beach deposit.

CUMMINGS MEMBER

The Cummings member is, principally, dark gray to black shale containing abundant pyrite and Foraminifera. Beds of "salt-and-pepper" sand are not uncommon, and a coal seam occurs near the base in the type section. The thickness of this member varies from 0 to 90 feet in the Vermilion area. It thins toward the south and is absent in the vicinitv of Wainwright but it thickens toward the north and is probably a wedge edge of the Clearwater shale which is about 275 feet thick on the Athabaska River. The Cummings member can be differentiated from the quartz sands of the two adjacent units by the presence of flint or smoky quartz grains in its sand beds and by the presence of characteristic Foraminifera in its shales.

ISLAY MEMBER

The Islay member consists largely of unconsolidated quartz sand. The grains are well sorted, rounded, and somewhat frosted. Dark minerals are present only in small amounts. In the upper part several very thin coal seams occur. The Islay sand varies from 0 to 60 feet in thickness. It is absent in Anglo-Home Buffalo Coulee well No. 1 which is on a Paleozoic limestone "high" where the Mannville formation is thinnest. Heavy oil occurs in the upper part of this member in five wells in the Vermilion area. The upper limit of the Islay member is placed at the highest occurrence of quartz sand below the Tovell member. In the Borradaile district it is overlain by a coal seam 1 or 2 feet thick.

TOVELL MEMBER

This member consists largely of massive coarse "salt-and-pepper" sandstone, gray shale with abundant plant remains, and some thin coal seams. The sandstones are composed of angular grains of quartz and dark gray flint or smoky quartz. The grains have a maximum size of 1 millimeter. Because of poor sorting and the presence of considerable quantities of fine-grained interstitial mineral matter, the Tovell sandstones have a low permeability. In places the sandstones are firmly cemented with calcium carbonate to form a hard dense rock. Plant material is abundant in the shales and the occurrence of large well preserved fronds suggests that they are *in situ*. No leaves of deciduous trees were found in the Tovell member or any other member of the Mannville formation.

The thickness of the Tovell member in its type section is 78 feet. Throughout the Vermilion area its thickness varies from 75 to 116 feet. The maximum thickness was encountered in the Northwest Tovell well No. 1, where the Mannville formation as a whole is exceptionally thick.

The Tovell member is underlain conformably by the Islay member and is overlain by the Borradaile member. It is differentiated from both of these by the abundance of dark minerals in its sands and by its angular and poorly sorted sand grains.

BORRADAILE MEMBER

Unconsolidated well sorted and rounded quartz sand with an average grain size of 0.15 millimeter comprises this member. Spherical pyrite nodules with a maximum diameter of one inch are common. Gray shale containing woody plant fragments is also present. The top of this member is the productive sand of the Borradaile field, where the member can be recognized in electric logs because of the fact that the self potential curve representing it is divided into three or four maxima suggesting higher permeability than in the adjacent members.

In its type section the Borradaile member has a thickness of 29 feet. In the Anglo-Home Buffalo Coulee well No. 1, this sand is absent. From there its thickness increases northward to a maximum known thickness of 60 feet in the Borradaile oil field.

O'SULLIVAN MEMBER

The O'Sullivan member is made up of chiefly "salt-and-pepper" sandstone, gray shale, and several prominent coal seams. The sands in the upper part of the member are more porous and do not contain many minerals whereas the sands in the basal part are fine-grained, poorly sorted, and contain a considerable proportion of dark gray chert and are interbedded with silt, silty shale, and coal seams. As a result, the lower half of the O'Sullivan member, which is considerably less permeable than the upper half, does not cause so great a self potential on the electric logs.

The O'Sullivan member reaches its maximum thickness of 155 feet in the Northwest Mannville well No. 1. This decreases to a minimum of 130 feet in the Borradaile district. The thickness of this member is more uniform than that of any of the other members of the Mannville formation, possibly because it was deposited on a more even floor resulting from the filling in, by the earlier members, of the irregularities caused by the uneven Paleozoic surface. The Borradaile member is the uppermost in the Mannville formation and it is overlain by the Lloydminster shale.

LLOYDMINSTER SHALE

Name and type locality.—Prior to 1930, the name "Benton shale" was used for all the beds between the Blairmore formation and the Belly River sands in Turner Valley, Alberta. As Hume pointed out (1930), the name is inappropriate because these beds are equivalent to the Benton, Niobrara, and the lower part of the Pierre. He therefore proposed the name "Alberta" for all the strata be-

tween the Blairmore and Belly River at Turner Valley. Later workers extended the use of the name to the Plains. "Alberta shale" was used in the Vermilion area, not in the sense of its original definition, but as a name for the shale underlying the Lea Park shale and overlying the "Lower Cretaceous" non-marine beds. The top of the "Alberta shale" in the Vermilion area was placed at the highest occurrence of speckled shale. Because this is a misuse of the name Alberta the term "Lloydminster shale" is here proposed for the marine shale overlying the Mannville formation and extending stratigraphically upward to the top of the highest bed of dark gray flaky speckled shale.

The name is derived from the town of Lloydminster near the Lloydminster gas well No. 2 which is taken as the type locality. The Lloydminster shale in this well occurs between the depths 960 and 1,690 feet (*cf.* Lloydminster No. 3, Wickenden, 1941, pp. 148–50).

LLOYDMINSTER GAS WELL NO. 2

Location.—SW. Sec. 12, T. 50 N., R. 28 W., 3d Meridian.
Elevation.—2,105 feet. Depths in feet.
Drilling method.—Cable tools.

GLACIAL DRIFT
0– 150 Gray clay and brown sand
RIBSTONE CREEK
– 170 Greenish gray fine-grained sand
LEA PARK SHALE
– 950 Massive gray shale, microfossils and pyrite
LLOYDMINSTER SHALE
–1030 Dark gray flaky shale, fish scales
–1120 Dark gray flaky shale, white calcareous specks
–1690 Shale, dark gray, silty at 1,430
MANNVILLE FORMATION
–1700 Coarse quartz sand
–1720 Gray shale and silt
–1780 Coarse quartz sand, coal at 1,740
–1800 Coarse- and medium-grained salt-and-pepper sand
–1820 Gray silt and some gray shale fragments
–1830 Gray sand
–1900 Gray shale, coal at 1,860
–2237 Sand and gray shale
DEVONIAN
–2330 White limestone, coarse quartz sand cavings

Lithology.—The Lloydminster shale consists mainly of dark gray flaky marine shale with white calcareous specks, some lighter gray massive shale, and some sand lenses. The upper 100–150 feet or so is dark gray shale which contains small white calcareous specks with an average diameter of 0.2 millimeter. The flaky character of this shale is especially noticeable under the microscope. Fish remains, mainly scales, are abundant. Foraminifera are rare or absent. Small white collophane spheres having an average diameter of 0.2 millimeter are abundant. This speckled shale grades downward into about 125 feet of lighter gray more massive shale in which calcareous specks are rare (Hume and Hage, 1941, p. 17). This shale without calcareous specks is underlain in many localities by 400–500 feet of dark gray flaky shale containing white calcareous specks. This lower speckled shale was not recognized in Lloydminster No. 2.

The cause of the white specks has not been explained conclusively. A study of exceptionally well developed specks in the cores of the Clonmel well No. 1 at Bruderheim, west of the Vermilion area confirms the hypothesis that the specks are part of the decomposed lamellar aragonite inner layer of *Inoceramus* shells. All gradations between the typical white specks and recognizable fragments of shells of *Inoceramus* were observed. J. C. Sproule,[3] geologist for the Imperial Oil Company, has observed that in southern Saskatchewan the white specks are Foraminifera of the genus *Globigerina.*

In the Viking-Kinsella district this lower speckled shale zone of the Lloydminster shale is underlain by the Viking gas sand from which gas is obtained to supply the city of Edmonton. This is a fine-grained irregularly bedded sand varying in thickness from 0 to 40 feet. It is absent at Vermilion and Lloydminster. It is probably the extension of the Blackleaf sandy member of southern Alberta.

The remaining 140 feet of strata below the Viking gas sand consists of gray massive bentonitic shale which becomes more bentonitic near the base and causes drillers of cable-tool wells trouble in keeping the casing moving through it due to its expansion in contact with the drilling fluid.

These bentonitic beds of the Lloydminster shale may be synchronous with the Crowsnest volcanics at the top of the Blairmore in the Rocky Mountains. The lower 15 feet of Lloydminster shale contains abundant specimens of *Inoceramus*, oysters, and arenaceous Foraminifera.

The Lloydminster shale was encountered between the depths 890 and 1,660 feet in the Atlas Vermilion well No. 1 in Legal subdivision 12, Sec. 32, T. 50 N., R. 5 W., 4th Meridian. The following is a description of the cable-tool samples of the Lloydminster shale from the well.

Depths in Feet	
850– 900	Dark gray shale with white calcareous specks
– 930	Dark gray shale as above, white collophane spheres 0.3 mm. in diameter
– 980	Shale as above, *Dictyomitra multicostata* abundant
–1050	Dark gray flaky shale
–1160	Dark gray shale with white specks, *Globigerina cretacea, Globigerina* n. sp. *Gümbelina globulosa*
–1180	Dark gray flaky shale, *Globigerina cretacea, Gümbelina globulosa*
–1210	Dark gray shale, *Haplophragmoides* n. sp.
–1230	Dark gray shale, *Globigerina* n. sp. abundant
–1390	Dark gray flaky shale, white calcareous specks
–1460	Dark gray flaky shale, *Ammobaculites fragmentaria, Miliammina manitobensis, Haplophragmoides* sp.
–1660	Missing
Mannville formation	

The occurrences of *Globigerina* and *Gümbelina globulosa* is rather characteristic of the central part of the Lloydminster shale. This zone of pelagic Foraminifera is widespread and can be followed through the Mid-Continent region of the United States into Texas where it is represented by the Eagle Ford formation (*cf.* Moreman, 1927, p. 91). About 112 miles northeast of Lloydminster at the

[3] Personal communication.

south end of Green Lake this zone of abundant *Globigerina* is associated with *Inoceramus labiatus*, which is also common in the Eagle Ford of Texas. Toward the east from Alberta, *Globigerina* becomes more and more abundant as the Lloydminster shale becomes thinner, and in Manitoba, Minnesota, and Iowa chalk beds occur which may represent the Cretaceous analogs of the *Globigerina* oozes of the present ocean (Calvin, 1895, pl. 19).

Formation boundaries.—The Lloydminster shale is underlain conformably by the Mannville formation. The contact is placed at the base of beds predominantly dark gray marine shale. These are ordinarily underlain by medium-grained Mannville sand. In the Anglo-Home Buffalo Coulee well No. 1 the dark gray shale is underlain by a coal seam which in turn is underlain by 10 feet of marine shale succeeded below by non-marine shale and sand of the Mannville formation. This is the only place in the Vermilion area where doubt exists concerning the base of the Lloydminster shale. Available evidence suggests that no hiatus occurs at this contact.

The Lloydminster shale is conformably overlain by the Lea Park shale. The nature of the contact in cores indicates that it is probably a gradational contact. The uppermost bed of the Lloydminster is dark gray flaky commonly speckled shale containing abundant fish scales and white spheres of collophane but without Foraminifera.

Thickness.—The thickness of the Lloydminster shale varies from 690 to 800 feet in the Vermilion area. It thickens south and west; in southern Alberta it is overlain by the Milk River sandstone and is about 1,500 feet thick.

Differentiating features.—The Lloydminster shale may be differentiated from the overlying Lea Park shale by its darker color, its flaky character, its white calcareous specks, and by the abundance of fish scales. The lower part of the Lea Park is lighter gray, slightly silty, has a conchoidal fracture, and contains abundant pyrite and Foraminifera. Under the microscope these features are more easily observed and the upper limit of the Lloydminster shale is readily recognized in the samples.

LEA PARK SHALE

Lithology.—The Lea Park, for the most part, is massive silty gray shale and argillaceous silt. Limestone and clay-ironstone concretions containing fossil molluscs are numerous.

The upper 200 feet of the Lea Park shale consists of silty shale containing plant fragments and nuculid pelecypods together with some gray clay-shale and thin lenses of fine-grained sand. Two prominent "floods" of Foraminifera occur in this interval; one 30 feet below the top of the formation is characterized by a new species of *Bulimina.* The other, 200 feet below the top occupies 30 feet of beds and is made up of abundant specimens of a new species of *Anomalina*, associated with a few specimens of *Neobulimina canadensis* Cushman and Wickenden. Pyrite, having a structure which under the microscope appears similar to oölitic structure, is associated with the Foraminifera in this lower bed.

On the North Saskatchewan River, in core tests that penetrated the lower part of the Lea Park, some of the disintegrated samples were about 90 per cent glauconite. Several varieties of pyrite occur. The micro-oölitic pyrite is not plentiful. Most of the pyrite is crytalline and shows crystal faces. There is an alternation of beds containing pale crystalline pyrite or marcasite with those containing deep bronze pyrite. The two types do not occur together, and the various "zones" of these are very helpful in local correlations.

Foraminifera are abundant in the middle and lower part of the Lea Park formation. This interval was penetrated in the Imperial core test No. 82 in Legal subdivision 16, Sec. 24, T. 56 N., R. 7 W., 4th Meridian. Core test No. 82 commenced about 200 feet in the Lea Park; the log follows.

Depths in Feet

ALLUVIUM

0– 46 Sand and gravel

LEA PARK SHALE

– 70 Gray shale, *Neobulimina canadensis, Haplophragmoides kirki, Dictyomitra multicostata, Anomalina* sp., *Bulimina* sp., *Gümbelina* sp.

–120 Gray shale, *Bulimina* sp., *Bolivina* sp., *Globigerinella aspera, Dentalina* sp., *Gyroidina* sp., *Neobulimina canadensis, Robulus* sp.

–140 Gray shale, *Bolivina* sp., *Gaudryina painoides, Neobulimina canadensis, Haplophragmoides kirki*

–350 Gray shale, *Bathysiphon* sp., *Neobulimina canadensis, Bolivina* sp., *Dentalina* sp., *Gyroidina* sp., *Bulimina* sp., *Gaudryina painoides, Robulus* sp.

–360 Gray shale, *Dictyomitra multicostata, Globigererinella aspera, Cytheridea* sp.

–370 *Globigerinella aspera, Epistomina* sp., *Robulus* sp., *Globigerina* cf. *cretacea.*

–385 Gray shale, *Robulus* sp., *Bathysiphon* sp. (rare), *Anomalina* sp., *Dictyomitra multicostata, Epistomina* sp.

–430 Gray shale, *Anomalina* sp., *Dictyomitra multicostata, Epistomina* sp.

–450 Gray shale, *Trochammina ribstonensis* (abundant)

–460 *Trochammina ribstonensis, Gaudryina* sp.

LLOYDMINSTER SHALE

–470 Dark gray, flaky shale with some white calcareous specks

Beds between the depths 46 and 360 feet are from the central part of the Lea Park and are characterized by a rich and varied microfauna of which the most useful index species are: *Neobulimina canadensis, Bathysiphon* n. sp., *Bolivina* n. sp., and *Globigerinella aspera.* The beds between 360 and 430 feet may be termed the *Epistomina* zone. This zone is characterized by two species which are restricted to it and have a wide distribution in Alberta and Saskatchewan: *Epistomina* n. sp. and *Anomalina* n. sp. The beds between 430 and 460 feet may be designated the *Trochammina ribstonensis* zone. *Trochammina ribstonensis* is restricted to this layer even though it is only 20 to 30 feet thick, and has a wide distribution in the Prairie provinces of western Canada (Wickenden, 1932A). This is the lowermost zone of the Lea Park shale.

Formation boundaries.—The Lea Park is underlain conformably by the Lloydminster shale. The upper contact is placed where darker gray flaky speckled shale first appears in the samples.

The Lea Park grades upward into the Ribstone Creek sand in the Vermilion area. As the lower Ribstone Creek sand thins out toward the east the Vanesti,

Grizzly Bear, and Mulga tongues join with the Lea Park to form one inseparable body of shale (Fig. 5).

Thickness.—No information is available as to the total thickness of the Lea Park at its type locality because its top has been eroded and its base is not exposed. Throughout the Vermilion area its thickness varies between 700 and 800 feet. In general, the Lea Park thickens northeast.

The variation in thickness of the Lea Park shale may be explained by the following theory. Two factors govern the thickness of the Lea Park. First, sedimentation was slower in districts on the northeast, farther away from the sources of the Lea Park shales. Second, the upper limit of the Lea Park occurs at higher stratigraphic levels on the northeast because marine conditions lasted longer there. The latter factor dominated over the former to cause a thickening of the formation on the northeast.

VANESTI TONGUE

Because of the scarcity of outcrops in the Vermilion area, the presence of a tongue of marine shale which projects into the upper part of the Ribstone Creek formation was not known prior to the summer of 1942. Outcrops of the shale of the Vanesti tongue were assigned previously to the Grizzly Bear tongue. At the mouth of Grizzly Bear Coulee and on the banks of Battle River in this vicinity, about 210 feet of shale crops out. In the center of this shale there is a poorly exposed sand bed containing oysters. The sand bed is 10 to 20 feet thick and crops out on the spur which separates Battle River Valley from Grizzly Bear Coulee near the junction of these two, at an elevation of 2,035 feet. Hume (1936) considered this sand to be the base of the Birch Lake sandstone largely because of the oysters it contains and because it is underlain by 100 feet of shale which, under the existing classification, he was forced to assign to the Grizzly Bear shale. He classified the sandstone which crops out lower on the valley slope at an elevation of 1,887 feet as the top of the Ribstone Creek formation (Hume, 1936, p. 11). One and a half miles east along the road which leads to Vanesti, there are numerous slumped outcrops of Grizzly Bear shale of which the top is at an elevation of about 2,140 feet. The oyster-bearing sand bed previously mentioned can be traced up Grizzly Bear Coulee where it is the aquifer for numerous springs at the base of the Grizzly Bear tongue. This same sand stratum can be traced up Battle River Valley where it thickens in a short distance into a bed of 50 feet or more thick. These observations, which were also made independently by W. Nygren of the Standard Oil Company of California, prove the presence of two equally prominent marine shale tongues which thin in a short distance toward the west. Various parts of these two tongues were noted in the Battleview Syndicate core test holes. The upper tongue is the Grizzly Bear. The lower one the writer here names the "Vanesti tongue," after the Vanesti district east of the outcrops in Battle River Valley (Fig. 4).

The type section of the Vanesti tongue comprises two outcrops. One outcrop is on the spur which divides Battle River Valley from Grizzly Bear Coulee near

the junction of the two, in Legal subdivision 8, Sec. 35, T. 47 N., R. 5 W., 4th Meridian. The other outcrop is on a spur in Legal subdivision 14, Sec. 25, T. 47 N., R. 5 W., 4th Meridian.

The Vanesti tongue is composed of gray shale and silty shale similar to the upper 200 feet of the Lea Park. The lower 60 feet is clay shale with a conchoidal fracture which grades upward, through silty shale, to silt and fine sand at the top.

The basal contact of the Vanesti tongue is placed at the top of a fairly persistent coal seam which was cored in the Battleview Syndicate core tests Nos. 3,

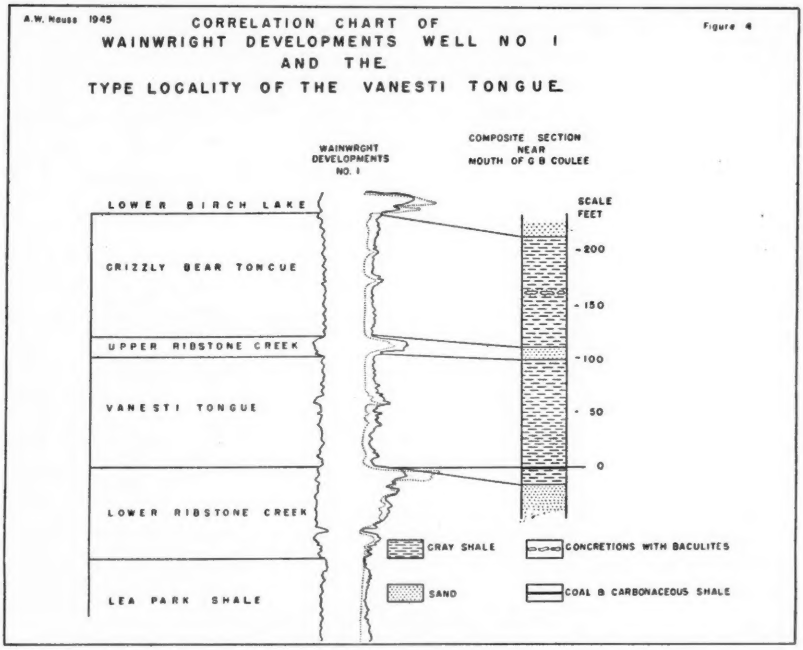


FIG. 4

4, 5, and 6A. The upper contact of the tongue is gradational and is placed at the base of the sand of the upper Ribstone Creek.

The Vanesti tongue has also been encountered north and west of Vermilion. It occurs in the Northwest Tovell well No. 1 between the depths of 16 and 108 feet. It crops out on the north bank of Vermilion River Valley in Legal subdivision 4, Sec. 34, T. 50 N., R. 8 W., 4th Meridian. On the Innisfree sheet (Hume and Hage, 1941) the window on Vermilion River mapped as Lea Park shale is part of the Vanesti tongue.

GRIZZLY BEAR TONGUE

The Grizzly Bear shale was named by Slipper (1918) from outcrops of dark gray shale on Grizzly Bear Coulee near its mouth (Fig. 1). Although he did not

designate a type locality, prominent outcrops are sufficiently rare along Grizzly Bear Coulee to indicate that Slipper had in mind those exposures near the mouth of the creek.

Here the shale is gray to black and is darker than the Lea Park shale. Fifty feet above the base are numerous clay-ironstone concretions which contain well preserved large *Baculites* cf. *grandis* Hall and Meek. These concretions are embedded in a thin stratum of sandy shale. In core tests near Mannville, the lower 20 to 30 feet of the Grizzly Bear is a clay shale with conchoidal fracture and contains many large specimens of a new species of *Haplophragmoides* associated with an ostracode of the genus *Cytheridea*. The upper 30 feet of the Grizzly Bear tongue becomes more silty toward the top and grades upward into fine-grained buff sand.

The lower contact of the Grizzly Bear is sharp. At its type locality it is underlain by 10 feet of upper Ribstone Creek sand which supplies the water for several springs half-way up the banks of the coulee. At the Northwest Mannville well No. 1 the shale is underlain by a coal seam 2 feet thick. The upper contact of the Grizzly Bear tongue is gradational. The clay shale of the lower part becomes gradually more silty upward and grades into the sand of the lower Birch Lake.

The Grizzly Bear tongue is absent west of Minburn and Fabyan, from where it thickens eastward to a maximum of 110 feet. Still farther east the sand bed dividing the Grizzly Bear and Vanesti tongues probably disappears (log of Lloydminster No. 3, Wickenden, 1941).

It is believed that the Grizzly Bear tongue does not occur west of a line joining Beauvallon, Minburn, and Fabyan. This line is thought to have been the farthest west advance of the mud-line in the Grizzly Bear sea.

MULGA TONGUE

Mulga is the name given by the writer to a marine shale tongue 150 feet above the top of the Grizzly Bear encountered in four core tests south of Mannville. In the Imperial core test No. 44 (Fig. 1) this shale was cored between the depths 121 and 152 feet.

Imperial Oil Core Test No. 44

Location.—Legal subdivision 13, Sec. 14, T. 49 N., R. 9 W., 4th Meridian.
Elevation.—2263 feet. Depths in feet.
Log of samples

GLACIAL DRIFT

0– 22 Boulder clay
– 45 Yellow and gray sand
– 46 Gravel
– 80 Yellow clay, fine gravel and sand

Log of cores

UPPER BIRCH LAKE

– 95 Coarse yellow soft angular salt-and-pepper sandstone
–110 Yellow medium-grained very soft sandstone
–120 Thinly bedded fine-grained soft sandstone, abundant plant remains
–121 Hard reddish brown argillaceous siderite

Mulga tongue

–145 Gray shale, with silt lenses and plant material, *Haplophragmoides* sp.
–147 Gray shale with conchoidal fracture, pyrite, *Haplophragmoides* sp.
–152 Laminated gray shale, plant material

LOWER BIRCH LAKE
-240 Medium-grained gray salt-and-pepper sand, carbonaceous laminae
-258 Laminated gray shale and very thin silt laminae
-263 Sand
-264 Hard medium-grained gray calcareous sandstone
-275 Sand and sandstone

This section is designated its type locality. The tongue consists of 20–40 feet of massive dark gray shale with fine silt lenses and without plant remains.

The Mulga tongue is underlain by medium-grained lower Birch Lake sand and is overlain by medium-grained upper Birch Lake sand. Its lower contact is sharp whereas the upper contact is gradational, again supporting the generalization that the marine shale members in the Vermilion area have sharp lower contacts but gradational upper ones. The same phenomenon was observed by Sears, Hunt, and Hendricks (1941) in New Mexico. They explain it as being due to sedimentation in a continually sinking basin. When the rate of accumulation exceeds the rate of sinking the basin gradually becomes filled, and continued deposition results in coarser non-marine clastics, which rest with a gradational contact on the subjacent marine shale. Later, when the rate of submergence surpasses sedimentation, the sea spreads over the low coastal plain with a rapidity which is a consequence of the lowness and flatness of the terrane, and which results in marine shale lying with a sharp contact on the subaerial detritus. This hypothesis can be readily accepted as an explanation for the phenomenon in the Vermilion area.

The Mulga tongue may be the correlative of the Shandro shale on the North Saskatchewan River (Allan, 1918) and of the shale at the base of sand on Birch Lake. The localities where the Shandro shale crops out are farther west than the interpreted "mud-line" of the Grizzly Bear sea, and Allan reports 325 feet of beds between the Shandro shale and the top of the Lea Park. At its type locality, the Mulga tongue is about 380 feet above the top of the Lea Park shale. This stratigraphic position and the fact that both are marine shales suggest a correlation of the Mulga tongue with the Shandro. If such a correlation should be confirmed, the name Shandro should replace the name Mulga.

The correlation of the Mulga tongue with the shale on Birch Lake is suggested by the regional structure; the two localities are in a line parallel with the strike of the beds and the two shales occur at the same elevation.

BELLY RIVER GROUP

The name Belly River was proposed in 1883 by G. M. Dawson for: "a series of pale, generally grayish and arenaceous beds at least two hundred feet in thickness—underlying the Pierre shales—on both the Bow and Belly rivers and elsewhere." The "Pierre shales" are now known by the name Bearpaw. Tyrrell (1887) was the first to use the name Belly River for the sandy beds which underlie the Bearpaw shale in the Vermilion area. Such use is amply justified, but because these sandy strata can be subdivided into several smaller units, the Belly River is regarded by the writer as a group of formations.

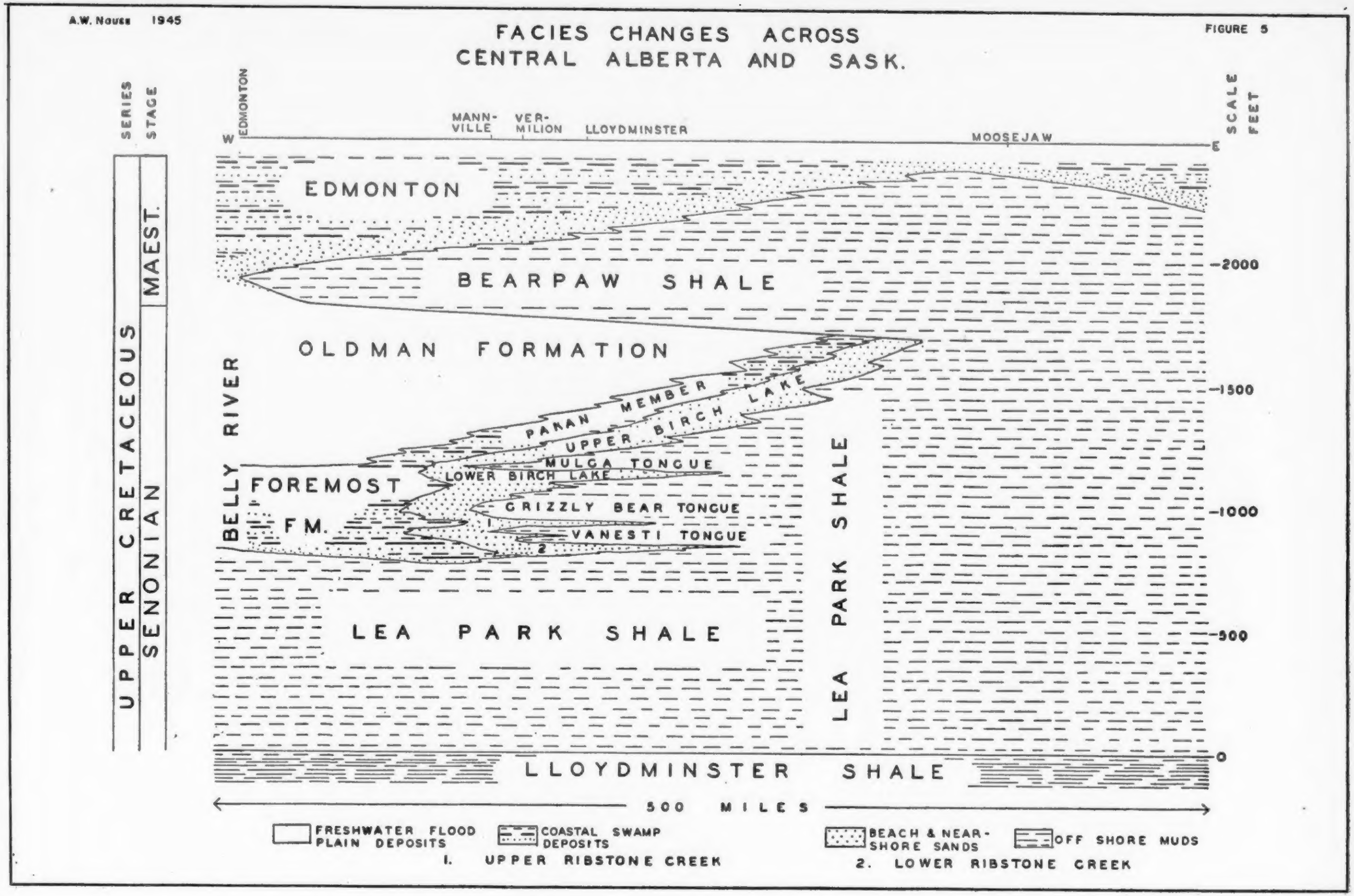

A.W. Nauss 1945
FACIES CHANGES ACROSS
CENTRAL ALBERTA AND SASK.
FIGURE 5
SERIES
STAGE
UPPER CRETACEOUS
MAEST.
SENONIAN
W
EDMONTON
MANN-VILLE
VER-MILION
LLOYDMINSTER
MOOSEJAW
E
SCALE FEET
EDMONTON
BEARPAW SHALE
OLDMAN FORMATION
BELLY RIVER
FOREMOST FM.
PAKAN MEMBER
UPPER BIRCH LAKE
MULGA TONGUE
LOWER BIRCH LAKE
GRIZZLY BEAR TONGUE
VANESTI TONGUE
1
2
LEA PARK SHALE
LEA PARK SHALE
LLOYDMINSTER SHALE
-2000
-1500
-1000
-500
0
500 MILES
FRESHWATER FLOOD PLAIN DEPOSITS
COASTAL SWAMP DEPOSITS
BEACH & NEAR-SHORE SANDS
OFF SHORE MUDS
1. UPPER RIBSTONE CREEK
2. LOWER RIBSTONE CREEK

FIG. 5

The Belly River is a group of near-shore and fresh-water formations consisting of fine to coarse sands and sandstones, non-marine shales, and coal seams.

The thickness of the Belly River group is at the maximum in the eastern ranges of the Rocky Mountains and it decreases eastward. Shales gradually take the place of sands as the distance from the mountains increases; tongues of shale appear and thicken at the expense of the intervening continental sediments till finally at Moosejaw, Saskatchewan the Upper Cretaceous is almost entirely shale (Wickenden, 1932C). The Belly River in the west is the same in age as the upper part of the Lea Park shale in the east (Fig. 5).

Four units are assigned to the Belly River group in the Vermilion area.

Oldman formation (Fig. 5)
Pakan member
Birch Lake sandstone
Ribstone Creek sandstone

These are described in order from oldest to youngest.

RIBSTONE CREEK SANDSTONE

Lithology.—This unit consists largely of medium-grained friable sandstone. In many localities it is cemented with calcite into a hard gray slabby rock which weathers to a buff or light yellow color. This induration is irregular and some indurated bands may be followed for only a few feet while others may be traced for a mile or more. The sands are generally cross-bedded and consist of approximately equal amounts of angular clear quartz and black and greenish chert. Woody plant fragments are common. In the western part of the area, thin coal seams and carbonaceous shales are interbedded with sand and gray shale in which abundant plant leaves and stems occur.

Formation boundaries.—The lower contact of the Ribstone Creek sandstone is gradational. The silty shale of the Lea Park grades upward through laminated silt into the fine sand of the basal Ribstone Creek.

The Ribstone Creek is divided into an upper and a lower part by the Vanesti tongue. The contact between this tongue and the lower Ribstone Creek is sharp. The upper Ribstone Creek is a thin sand member which is about 40 feet thick near Mannville and thins eastward. It is fairly porous and is the aquifer for numerous water wells in the Vermilion area.

BIRCH LAKE SANDSTONE

Lithology.—The Birch Lake sands are similar to those of the Ribstone Creek. However, the Birch Lake sandstone, as a formation, differs in being more massive and slightly coarser. Large sandstone concretions, which are distinct from the sandstone slabs of the Ribstone Creek, are common, but the units can not everywhere be recognized by this character. The greenish gray Birch Lake sands tend to weather to a rust color rather than the light yellow of the Ribstone Creek.

Near the head of Grizzly Bear Coulee a fossiliferous sandstone bed crops out

25 feet above the base of the Birch Lake sandstone. It forms a terrace on the banks of the coulee because of its resistance to erosion. The same bed can be seen in a cut on the north bank of Buffalo Coulee near its mouth, where it contains abundant shark teeth, pelecypods, and some teeth of carnivorous dinosaurs.

Formation boundaries.—The gradational nature of the basal contact is well demonstrated in an outcrop on the south side of Grizzly Bear Coulee on the Wainwright-Vermilion road. The upper contact is placed at the base of the lowest coal or carbonaceous shale bed of the overlying Pakan member. All the beds predominantly sand, similar to those exposed at the north end of Birch Lake, are placed in the Birch Lake formation.

Thickness.—The thickness of this unit has been given as 50–100 feet (Hume and Hage, 1941). However, in the Imperial core test No. 44, 165 feet of massive sand was cored. All of this is assigned to the Birch Lake because of its lithologic similarity to the beds at the type locality of the Birch Lake. Other core tests and a few outcrops in this same district reveal that the thickness of the Birch Lake sandstone, as already defined, is about 200 ft.

The Mulga tongue divides the Birch Lake into an upper and a lower part in the district south and west of Mannville where the lower Birch Lake has a thickness of 150 feet.

PAKAN MEMBER

The Pakan member was formerly known in the Vermilion area by the informal name "Variegated beds." A better term is "Pakan" which Allan (1918) proposed for the member from outcrops on the North Saskatchewan River.

Outcrops of this unit are rare in the Vermilion area. The best one is in the railway cut $\frac{1}{4}$ mile west of the station of Hawkins. This is an exposure of 40 feet of carbonaceous shale, fine argillaceous sands, coal, and non-marine gray shale overlying the massive, rust-colored Birch Lake sand. Allan reported a thickness of 225 feet for this unit on the North Saskatchewan River. The coal and carbonaceous shale of this unit were probably deposited in coastal swamps. The member is differentiated from the Birch Lake by the occurrence of coal, carbonaceous shale, and non-marine gray shale.

OLDMAN FORMATION

This formation was formerly known in east-central Alberta by the name "Pale beds." On the basis of lithology and stratigraphic position this formation may be correlated with the Oldman formation of southern Alberta; the name Oldman is therefore applicable in the Vermilion region.

The Oldman formation crops out in the southwestern part of the Vermilion area. It is composed principally of light gray argillaceous and bentonitic sand with some beds of bentonite, thin seams of coal, carbonaceous shale, and clay-ironstone bands (Hopkins, 1923). Slipper estimated the thickness of this unit to be about 500 feet. A calculation based on the outcrop width and the regional dip gives a thickness of 400 feet. The Oldman formation grades upward into the Bear-

paw formation. It is the highest stratigraphic unit studied by the writer. For the salient points regarding higher units the reader is referred to Figure 2.

Geologic History

The various features of the stratigraphy of the Vermilion area may be explained by an hypothesis of geologic history. Although additional information may modify this hypothesis, that available at the present time suggests the following Cretaceous history for the Vermilion area.

LOWER CRETACEOUS

After a long period of pre-Cretaceous erosion which caused many irregularities in the surface of the gently inclined Devonian limestone, the Cretaceous sea advanced from the north to the vicinity of the Vermilion area. The beach sands of the Dina member of the Mannville formation accumulated along the shores. Again the sea advanced, this time to about 15 miles south of Vermilion and the marine muds of the Cummings member settled out of its quiet waters. Arenaceous Foraminifera lived and died in the partially land-locked bays along the coast. After the Cummings epoch the sea receded and on its beaches originated the glistening sands of the Islay member. The mouth of one of the rivers flowing northward shifted to the site of the Vermilion area at the end of the Islay epoch and in its delta the sands of the Tovell member collected. The river mouth migrated from the Vermilion area and the ocean waves reworked the upper part of the Tovell sands and rounded and sorted them to form the Borradaile member. Another shift brought the river mouth back to the Vermilion area and deposited the deltaic sands of the O'Sullivan member. In the coastal swamps near the delta, plant débris accumulated and formed coal seams of this member.

In picturing the conditions which resulted in the deposition of the Mannville formation, it is instructive to compare these sediments with those accumulating at the present time near the mouth of the Mississippi River. Mississippi River delta sedimentation was well described by R. J. and R. D. Russell (1939). The poorly sorted salt-and-pepper sands of the Mannville formation are analogous to the deposits in and along the distributaries and active passes. The well sorted quartz sands are comparable with the wave-worked sands of the beaches and offshore bars near the Mississippi delta. The coal seams of the Mannville formation had their origin in the delta marshes, and the marine shales of the Cummings member are similar to the marine muds of the open Gulf of Mexico. The superposition of these various environments was brought about by changes in the coast line such as that which accompanied the shift of the Mississippi mouth from the St. Bernard subdelta to its present site (Russell and Russell, 1939, Fig. 2).

UPPER CRETACEOUS

A general sinking of the whole province of Alberta, which may have resulted from the withdrawal of subcrustal material to form the Crowsnest volcanics in

the mountains, allowed the Upper Cretaceous ocean to advance to the foot of the Selkirk Mountains. In this sea the Lloydminster and Lea Park shales were deposited. The sea again retreated and the near-shore sands of the lower Ribstone Creek were deposited. Several advances and retreats of the sea followed, to cause the interfingering of near-shore sands and marine shales in the lower part of the Belly River group. When the Birch Lake sands were deposited, the shark-infested sea retreated to the northeastern part of the Vermilion area and the coal seams of the Pakan member were laid down in coastal swamps. In this hot, humid region dinosaurs lumbered through subtropical forest. Further retreat of the marine waters resulted in the deposition of the Oldman formation in the flood plains of the meandering rivers of that time. This sea did not retreat beyond the 3d Meridian in Saskatchewan, east of which there was continuous sedimentation of marine shale until the sea again advanced to make its final stand in the deposition of the Bearpaw shale.

Conclusions

1. In Upper Cretaceous time, a long period of accumulation of marine muds was followed by deposition of the Belly River near-shore sands and shales, which have rapid lateral variations.

2. The Mannville formation of Lower Cretaceous age may be divided into six members mainly on the basis of the presence or absence of dark minerals in the sands and the occurrence of marine shale.

3. The sediments of the Mannville formation and the association of the different types are markedly similar to sediments now forming on and near the Mississippi delta.

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VOL. 29, NO. 11 (NOVEMBER, 1945), PP. 1630-1653, 3 FIGS.

STRENGTH OF THE EARTH[1]

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ABSTRACT

Among the most perplexing problems in geologic science has been the persistent one of how an earth whose exterior is composed of hard rocks can have undergone repeated deformations *as if* composed of very weak and plastic materials. Tidal and seismological evidence indicates that the earth as a whole reacts to stresses of brief duration with a rigidity of the order of that of steel, while orogenic and gravitational phenomena suggest that the earth is non-rigid and very weak. In consequence of this apparently conflicting evidence recent views regarding the earth have ranged between the extremes of great rigidity and high fluidity.

It is here shown that this conflict of data is more apparent than real. By means of the principles of physical similarity it is possible to translate geological phenomena whose length and time scales are outside the domain of our direct sensory perceptions into physically similar systems within that domain. When we do this we discover that the behavior, in response to gravitational stresses in geologic space and time, of an earth composed of hard rocks and possessing a viscosity appropriate to the post-glacial uplifts in Europe and North America would be very similar to that of the weak plastic materials and viscous liquids of our everyday experience.

HISTORICAL PERSPECTIVE

Since the earliest days of geological science one of the most perplexing and persistent of all the problems of geology has been that arising from the observed deformation of the solid rocks of the earth. With the exception of a thin surface veneer of unconsolidated sediments, and the temporarily liquid magmatic rocks, the rocks of the lithosphere are observed to be solid, rigid, and strong; yet as seen in the mountains of the present time as well as those of the geologic past, the evidence is unmistakable that these same rocks, during geological history, have been repeatedly deformed as if composed of putty. The question of how solid rocks could thus be deformed has led to some of the most diverse opinions entertained in any domain of geological science.

In the early days of geology, when it was presumed that geological and Biblical chronology must coincide, and that the age of the earth since "creation" was only a few thousand years, the successive deformations of the earth were supposed to have been drastic and brief. Mountains were assumed to have been formed in a series of catastrophic upheavals of which contemporary earthquakes and volcanic eruptions were regarded as minor examples.

By the beginning of the nineteenth century, due in large measure to the work of John Hutton[3] in Scotland, geological synthesis had advanced to the point where it was realized that geologic time was long and that the deformations during the geologic past were probably not more spectacular than those occurring

[1] Manuscript received, July 14, 1945. Lecture delivered during March and April, 1945, before the affiliated societies of the Association under the auspices of the Distinguished Lecture Committee. This lecture is a further development of a theme whose fundamentals were established in the following paper:

M. King Hubbert, "Theory of Scale Models as Applied to the Study of Geologic Structures," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 1459–1520. Reprinted, November, 1944.

[2] Associate director, Exploration and Production Research, Shell Oil Company, Incorporated.

[3] Archibald Geikie, *The Founders of Geology*, London (1897).

at the present time. At the same time a simple mechanism for earth deformation was afforded by the nebular hypothesis of the origin of the solar system put forward by the French astronomer Laplace. According to this hypothesis, the earth formerly had been a sphere of molten rock. As it cooled, a thin surface crust was formed, and as the cooling progressed the accompanying shrinkage caused the crust to buckle repeatedly, thus producing the observed deformation of the earth.

Beginning about 1880 several new lines of evidence bearing on the problem began to develop. It was about this time that the first moderately satisfactory earthquake seismographs were constructed and put into operation. By the end of the century, or shortly thereafter, enough data on the transmission of elastic waves from distant earthquakes had been accumulated to validate some significant conclusions regarding the earth. Study of seismograms showed that, in addition to a type of wave motion which was propagated along the surface of the earth, there were compressional and shear-wave types which were propagated through the earth, the last type penetrating to depths almost half way to the center.

The significance of this lay in the fact that only a rigid body is capable of transmitting shear waves; and the observation that the earth transmitted such waves to great depths indicated that it was rigid to corresponding depths, at least to stresses of a few seconds duration. Furthermore, from the observed velocity of transmission and the approximately known density within the earth it was possible to show that the coefficient of rigidity was of the order of that of steel.

Coincident with the rise of seismology, another line of evidence bearing on this problem was emerging from the study of tidal phenomena. As early as the late 1870's, the investigations of William Thomson,[4] George Darwin,[5] and others had led to the conclusion that the response of the lithosphere to the tidal stresses produced by the sun and the moon was more like that of a rigid than a fluid body. Measurements of the tides in the lithosphere were made in the 1880's by George and Horace Darwin in England, and by E. von Rebeur-Paschwitz[6] (also one of the early seismologists) in Germany, in efforts to determine the rigidity of the earth. Their attempts, however, were only partially successful.

During the decade between 1910 and 1920, at the instigation of the geologist T. C. Chamberlin, this problem was again given active attention. An elaborate series of precise measurements of the tides in the lithosphere was made by the physicists A. A. Michelson and H. G. Gale[7] at Williams Bay, Wisconsin. Two pipes, each 502 feet long and 6 inches in diameter, were buried 6 feet underground,

[4] William Thomson and Peter Guthrie Tait, *Treatise of Natural Philosophy* (1883).

[5] George Howard Darwin, *The Tides*, Cambridge, Massachusetts (1899).

[6] George Howard Darwin, *op. cit.*, p. 133.

[7] A. A. Michelson and H. G. Gale, "The Rigidity of the Earth," *Jour. Geol.*, Vol. 27, No. 8 (1919), pp. 585–601.

one extending north and south and the other east and west. These were half filled with water and the differential movement between the water and the earth was measured continuously at each end of each of the pipes by automatically recording interferometers. The final measurements were made continuously from November 20, 1916, to November 20, 1917. The tides observed in the water in the pipes had an amplitude of 0.69 of the computed value on the assumption that the earth is ideally rigid, which indicated that the tide in the lithosphere had an amplitude of 0.31 of what it would have had if the earth were fluid. There was also a phase lag of 4° of the observed tides relative to the impressed forces.

The net result of these measurements was the conclusion that the response of the lithosphere to tidal stresses having a duration of about 12 hours was that of an almost perfectly elastic body with a rigidity about that of steel.

Prior to the end of the last century still another line of evidence regarding the internal properties of the earth was emerging. This concerned the period of the earth's free nutation, whereby there is a slight periodic shift of the axis of rotation of the earth with respect to the earth itself. Assuming the earth to be perfectly rigid, this period was computed to be 305 days; for a perfectly fluid earth, it should have been infinite; for an elastic earth it would lie between these limits. The observed period was found to 427 days, which corresponded to an elastic earth with a coefficient of rigidity comparable with that of steel.

It thus appeared that to stresses of a duration as great as a year the behavior of the earth as a whole was still that of a rigid rather than a fluid body.

Hence, by the early part of the twentieth century, the familiar conception of the earth with a thin solid crust and a liquid interior and the simple mechanism of earth deformation which it afforded was becoming increasingly untenable, yet there was nothing really adequate to take its place. How were the observed deformations of the solid earth to be accounted for if the earth to great depths possessed the rigidity of steel?

Complicating the problem further was still another line of evidence which had been developing since about the middle of the nineteenth century. In conducting the trigonometrical survey of India it was noted that the gravity field of the earth was distorted as the Himalaya Mountains were approached. This result was not unexpected since it was known that the mountain masses would attract according to the Newtonian law of gravitation. When, however, the observed distortion of the gravity field was compared with that computed from the approximately known extent of the mountains the surprising result obtained was that the distortion was only about a third as great as the visible mountains should have produced.

The date of this was about 1855 when, it will be recalled, an earth with a thin solid crust and a liquid interior was the prevailing conception. In considering the cause of the discrepancy an hypothesis was advanced by the Archdeacon Pratt[8]

[8] J. H. Pratt, "On the Attraction of the Himalaya Mountains and of the Elevated Regions beyond Them, upon the Plumb Line in India," *Royal Soc. Phil. Trans.*, Vol. CXLV (1855), pp. 53–100.

of Calcutta that the solid crust of the earth rested in floating equilibrium upon the liquid interior, and to satisfy this condition it was supposed that the bottom of the crust was a level surface with each vertical column of unit cross section above this containing the same mass. The average density of the crust would then vary inversely as its thickness, and surface features like the Himalaya Mountains would be buoyed up by the less dense crust. The abnormally low density of the crust under the mountains would also compensate for the gravitational attraction of the mountains so that the two together would distort the gravity field much less than the mountains alone.

Sir G. B. Airy,[9] Astronomer Royal of England, objected that it was improbable that the density of the earth's crust should vary in the manner suggested by Pratt. He thought it far more likely that the average density of the crust would be constant. Then, if the crust were in floating equilibrium on the denser subcrustal liquid, it would be necessary for it to protrude downward into the liquid under each mountain range.

This hypothesis, also, accounted for the observed distortion of the gravity field.

Finally, about 1900, our own Coast and Geodetic Survey encountered similar difficulties in their triangulation network so it was natural that they should turn to the precedent of the Indian Survey for a solution. They adopted a modified version of the Pratt hypothesis and found that in the United States, also, this hypothesis eliminated most of the discrepancies between the observed and computed gravity distortions.

The physical and geological implication of these results was that the earth appeared to lack strength great enough to support the mass of a respectable-sized mountain range, and that such topographic features required bolstering up by a process of flotation from below. This result appeared to be fairly well established by 1920 and the quandary into which it placed the students of the earth was extreme. On the one hand, they were confronted with the visual evidence of an earth composed of rigid and strong rocks, and the indirect evidence of an earth rigid to great depths, with no indication of the formerly supposed thin solid crust and liquid interior; on the other hand they had the geological evidence of the repeated deformations of these same strong rocks, and now to this was added further evidence of apparent extreme weakness.

It is not surprising that in such a situation the range of geological speculation should have been great. In one group were the defenders of the rigid-earth hypothesis with the auxiliary "doctrine of the permanence of continents and ocean basins"; in another were the apostles of fluidity, many of whom found it

———, "On the Deflection of the Plumb Line in India Caused by the Attraction of the Himalaya Mountains and the Elevated Regions Beyond; and Its Modification by the Compensation Effect of the Deficiency of Matter below the Mountain Mass," *ibid.*, Vol. CXLIX (1859), pp. 745–78.

[9] G. B. Airy, "On the Computation of the Effect of the Attraction of Mountain Masses as Disturbing the Apparent Astronomical Latitude of Stations in Geodetic Surveys," *ibid.*, Vol. CXLV (1855), pp. 101–04.

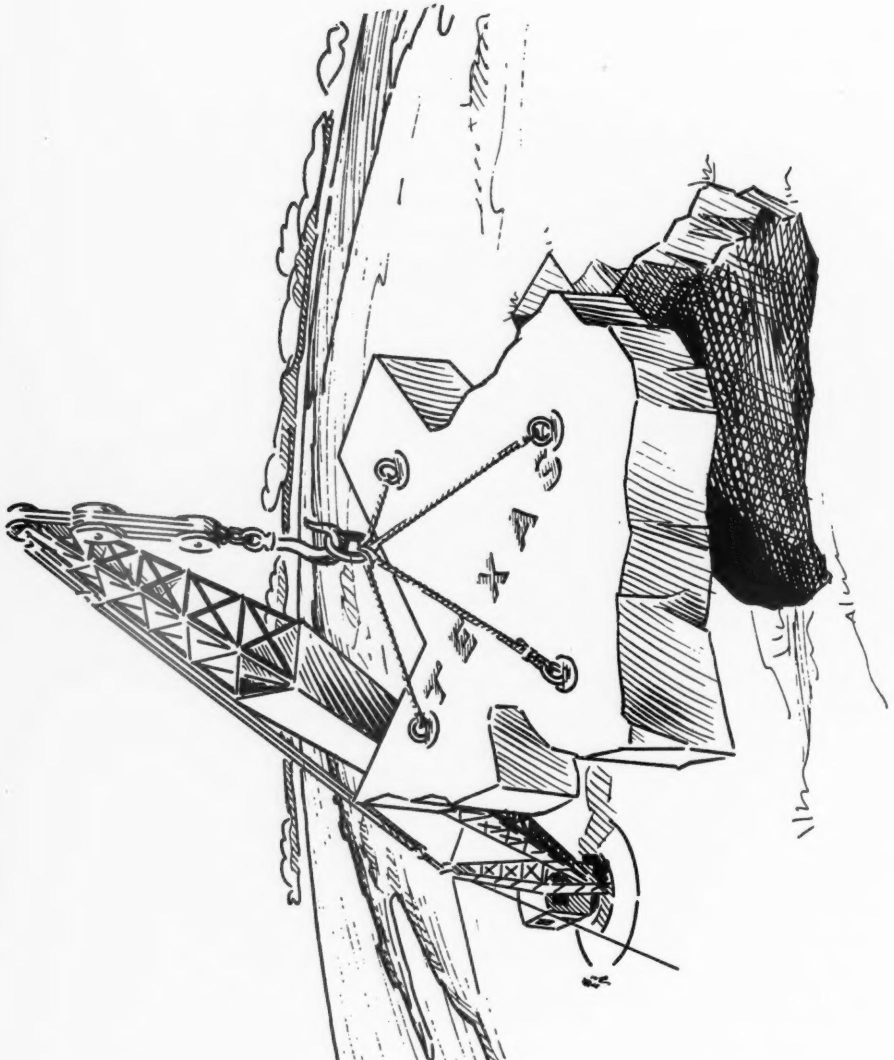

FIG. 1

possible to show to their own satisfaction that the uplift and depression of almost any area of more than a few tens of miles in breadth varied with the concurrent loading and unloading by erosion and deposition in almost perfect accordance with the dictates of the principle of isostasy, as the flotation hypothesis had come to be known. Even more extreme was the suggestion that not only were the continents in a state of flotation but they also were drifting about on the face of the earth. In fact, so contradictory were these opposing views that they have been rather aptly characterized as the "hard rock" theory versus the "soup" theory of the earth. Yet the rigid-earth school has found it difficult to account for the observed deformability of the earth; while the apostles of fluidity have found it necessary to resort to gratuitous subterfuges in the form of assumptions of a fluid or plastic substratum underlying a rigid crust, to circumvent the observed rigidity.

STRENGTH OF THE EARTH

To a considerable extent, these diversities of view have persisted to the present time and it will be one of the principal objects of the present discourse to see in what measure it may be possible to resolve the paradox in which we now find ourselves. To do this we shall at first make no concessions to the possibility that the strength of rocks to long-sustained stresses may actually be rather small. We shall, in fact, assume that the earth as a whole, as well as any extensive area of its surface, is composed of the strongest rocks known, and then inquire how strong such an earth would be in terms of its behavior under ordinary magnitudes of stress.

To render our problem specific, let us consider the quarrying operation illustrated in Figure 1. Here we suppose that we are able to quarry as a single block with a thickness roughly one-fifth of its width the entire state of Texas, and that we have a quarry crane capable of hoisting it. Let us suppose further that this block is composed of the strongest of rock and, moreover, that it is monolithic and flawless. The question to which we seek an answer is: Will the rock itself be strong enough to permit hoisting in this manner?

Before we attempt to answer this question let us consider another: How high can a man jump? In a standing vertical jump an average man can lift his center of gravity about 18 inches, or roughly one quarter of his height. If it were possible to enlarge such a man by two diameters without changing the specific strength or the density of his materials, could he then jump twice as high? If enlarged three diameters could he jump three times as high? Or, in general, should a man be able to jump one quarter of his height independently of his size?

Before answering this question let us ask ourselves still another: How much would he weigh? Here, if we should follow our first impulse and say he would weigh twice as much we should be wrong, for a little reflection will convince us that the man would now weigh not twice, but *eight* times as much as formerly. This is obvious when we consider that the weight is proportional to the volume and that a cube two units of length to the side has a volume of 8 cubic units,

which is eight times the volume of a cube 1 unit to the side. The same relationship obtains for any two similar bodies of any shape whatever. The ratio of their volumes is equal to that of their lengths raised to the power three. For an enlargement of three diameters the volume would be increased 27-fold, for four diameters 64-fold, and so for all higher factors of enlargement.

Now, a man's ability to jump depends both on his weight and on his gross strength. How strong would our enlarged man be? His gross strength is measurable by the force he can exert and this is proportional to the cross-sectional area of his muscles. The area, however, increases as the square of the linear factor of enlargement, so that for an enlargement factor of two the man would be four times as strong. Then with an eight-fold increase in weight and only a four-fold increase in gross strength, it is obvious that the ratio of his weight to his gross strength in the enlarged state would be just twice what it was in the original. By the same kind of reasoning this ratio would be, respectively, $3, 4, \cdots, n$ for enlargements of the corresponding amounts. It is thus seen that as the man is made continually larger the weight to be lifted rapidly out-distances his aggregate strength. Since a man can lift little more than four times his own weight at his normal size, it follows that an enlargement of four diameters would be about the limit for which he would be able to stand.

The same result may be obtained in a more obvious manner if we leave the man unchanged and increase gravity. The man's strength in this case is unaltered but his weight increases proportionally to the increase of gravity. Thus by doubling gravity we double the ratio of weight to strength, which is analogous to a two-fold enlargement leaving gravity unchanged. In the same manner an n-fold increase of gravity with the figure unchanged is analogous to an n-fold enlargement with gravity unchanged.

By varying gravity in this manner while leaving the man unchanged, for a two-fold increase in gravity a man weighing originally 150 pounds will now weigh 300 pounds; for a three-fold increase he would weigh 450 pounds; and for a four-fold increase, 600 pounds. It is clear, therefore, that his ability to jump would rapidly decrease with increase of gravity, and that a four-fold increase would about reach the limit of his ability to stand, which is analogous to the corresponding enlargement with gravity constant.

Going down the scale this relationship works in the opposite direction, for the enlargement factor is now fractional and the weight-to-strength ratio is also fractional and diminishes with the degree of reduction. Consider, for example, reducing a man by a factor of $1/50$. He would then be about 1.5 inches tall. His weight would be reduced by the factor $(1/50)^3$ and his aggregate strength by $(1/50)^2$, so that his weight-to-strength ratio would be $1/50$ of what it was originally, and he would be 50 times as strong in proportion to his weight. This is equivalent to leaving the man unchanged and reducing gravity to one-fiftieth of its former value. If the man could originally jump 1.5 feet high, he should now be able to jump about 75 feet high, or about twelve times his height. The reduced

man should jump an equivalent number of multiples of his height, or about 18 inches high.

Hence, a man reduced by this amount would be able to do a moderately acceptable imitation of a grasshopper!

Let us require now that the performance of the man in either an enlarged or reduced state be similar to his original performance. From the preceding discussion it is clear that this can be accomplished only by keeping the ratio of the man's weight to his aggregate strength constant for all sizes of enlargement. If the density is to be kept the same and gravity is unalterable, it follows that this can be done only by changing the specific strength of the man's materials by the same factor as his linear enlargement or reduction. Thus, if he were made n times as large he would require materials n times as strong; conversely, if he were reduced in size his materials would have to be proportionately weakened for similar behavior.

Let us accept, for the moment, this intuitively derived result as valid and apply it to the problem of lifting the state of Texas. Since the original assignment in this case is manifestly impossible of execution, suppose we imagine the block to be reduced to such a size that it can be lifted conveniently. What must the properties of this reduced block be in order that it should respond to lifting in the same manner as the original *if the latter could be lifted?*

In this case gravity will be unchanged and it will be convenient to keep the density the same, so we are left with the result that we must reduce the strength of the materials by the same amount as the length reduction. The state of Texas is about 1,200 kilometers wide and a convenient size for the reduction would be a width of 60 centimeters, or about 2 feet. This would correspond with a length reduction of 5×10^{-7}. Assuming the original to be composed of very strong rock, the crushing strength would be of the order of 30,000 lbs./in.^{2}. The strength of the properly reduced version should then be

$$30{,}000 \times 5 \times 10^{-7} = 0.015 \text{ lb./in}^2.$$

It is difficult to envisage a solid of this weakness. A crushing strength of 0.015 lb./in.^{2} is the same as 1 gm./cm.^{2}, which for a density of 3 gms./cm.^{3} would be the pressure at the base of a column one-third of a centimeter high. Any column higher than this would collapse under its own weight. Yet the size of the reduced block would be such that its thickness would be about 15 cm. (6 in.) and its total weight about 180 lbs. The pressure at its base would be about 45 gm./cm.^{2}, or 45 times the crushing strength of the materials.

Consequently, if we tried to lift such a block in the manner indicated in Figure 1, the eyebolts would pull out; if we should support it on a pair of sawhorses, its middle would collapse; were we to place it upon a horizontal table, its sides would fall off. In fact, to lift it at all would require the use of a scoop shovel. That this is not an unreasonable result can easily be verified by direct calculation upon the original block. For it, too, the pressure at its base would exceed the

crushing strength of its assumed material by a factor of 45. The inescapable conclusion, therefore, is that the good state of Texas is utterly incapable of self-support!

Before proceeding further, let us pause long enough to consider in more detail the process of reasoning we have just employed to see if we can formalize the procedure. When considering a problem which, because of the size or some other physical element involved, is outside the domain of our existing experience, we seek to find a way to transform the problem into a similar one whose physical elements are within that domain. This involves the concept of *physical similarity.* We are all familiar with the concept of geometrical similarity and in fact make use of it almost every day of our lives. For example, when we are interested in the relative positions of things, possibly oil fields, in an area much too large to be viewed at one time, we bring the area as a whole into the domain of our sense perceptions by means of a geometrically similar area, namely, a map. This small-scale figure is characterized by the fact that if l_1 is a length between two arbitrary points in the field, and l_2 the corresponding distance on the map, then for all corresponding pairs of such distances

$$\frac{l_2}{l_1} = L_r = \text{constant}, \tag{1}$$

where L_r is the scale of the map.

The same kind of reasoning applies when two systems are said to be physically similar. For physical similarity not only the length, but *all corresponding significant physical quantities* (areas, volumes, times, velocities, accelerations, masses, densities, moments of inertia, forces, stresses, strengths, viscosities, elastic moduli, moments, energies, and the like), *must bear constant ratios to one another.*

We are not at liberty, however, to assign arbitrary values to all of these various ratios because many of them are not independent of the others. If, for example, we assign an arbitrary value to the length ratio we at the same time determine the ratios of area and of volume. Corresponding areas can be subdivided into an equal number of similar squares. For each corresponding pair the ratio of the area is l_2^2/l_1^2, and for the total areas the ratio will be

$$\frac{A_2}{A_1} = \frac{nl_2^2}{nl_1^2} = L_r^2. \tag{2}$$

By the same reasoning, the ratio of corresponding volumes will be

$$\frac{V_2}{V_1} = \frac{nl_2^3}{nl_1^3} = L_r^3. \tag{3}$$

Similarly, the ratios of velocity and acceleration are determined jointly by those of length and time:

$$\frac{v_2}{v_1} = \frac{l_2/t_2}{l_1/t_1} = L_r T_r^{-1}, \tag{4}$$

and

$$\frac{a_2}{a_1} = \frac{l_2/t_2^2}{l_1/t_1^2} = L_r T_r^{-2}, \tag{5}$$

where v signifies a velocity, and a an acceleration.

Likewise the ratio of density is determined by the ratios of length and mass:

$$\frac{\rho_2}{\rho_1} = \frac{m_2/l_2^3}{m_1/l_1^3} = M_r L_r^{-3}. \tag{6}$$

In general, in the system in which we are interested there will be a limited number of physical quantities which are independent of one another and require independent units of measurement. Usually the choice of these is not unique, so that if n is the number of independent quantities required to specify a given physical system, there frequently will be several different sets of n quantities which can be taken as fundamental. Then all the other quantities are measurable and expressible in terms of the ones chosen. Thus, in a given system, let the n fundamental quantities be represented by

$$A, B, C, \cdots, K,$$

and let Q be a derived quantity. Then the unit of Q is expressible in terms of the units of the fundamental quantities by means of an expression of the form:

$$Q = A^a B^b C^c \cdots K^k, \tag{7}$$

where a, b, c, $\cdots$ and k are either integers or rational fractions.

Finally, let two such systems be physically similar. The fundamental scale ratios will then be

$$\left.\begin{aligned} \frac{A_2}{A_1} &= A_r \\ \frac{B_2}{B_1} &= B_r \\ \frac{C_2}{C_1} &= C_r \\ &\cdot\ \cdot\ \cdot\ \cdot \\ \frac{K_2}{K_1} &= K_r \end{aligned}\right\} \tag{8}$$

and, since the fundamental quantities are mutually independent, so too will these ratios be, and we shall be at liberty to assign to each of them any value which may be convenient. Then, in terms of the ratios of these fundamental quantities the ratio of any derived quantity is found, by combining equations 7 and 8, to be

$$Q_r = \frac{Q_2}{Q_1} = \frac{A_2{}^a B_2{}^b C_2{}^c \cdots K_2{}^k}{A_1{}^a B_1{}^b C_1{}^c \cdots K_1{}^k} = A_r{}^a B_r{}^b C_r{}^c \cdots K_r{}^k. \tag{9}$$

Let us illustrate this procedure in a concrete instance by applying it to our original problem of quarrying and hoisting the state of Texas. We wished to know what strength we should have to give to the reduced model in order for it to be physically similar to the original. In this problem it will be convenient (but by no means necessary) to choose *length, density,* and *gravity* as our fundamental quantities. Then the ratios of length, density and gravity will be the fundamental scale ratios. In terms of these the ratio of the strengths of the materials in the two cases will be determined. Now, specific strength is measurable in terms of stress, so the ratio of the strengths must be the same as that of corresponding stresses:

$$\frac{(\text{Strength})_2}{(\text{Strength})_1} = \frac{(\text{Stress})_2}{(\text{Stress})_1} = \frac{(\text{Force})_2/(\text{Area})_2}{(\text{Force})_1/(\text{Area})_1}$$

$$= \frac{m_2 g_2/A_2}{m_1 g_1/A_1} = \frac{\rho_2 L_2{}^3 g_2/L_2{}^2}{\rho_1 L_1{}^3 g_1/L_1{}^2} = L_r \rho_r g_r. \tag{10}$$

Hence the ratio of the stresses and of the strengths is equal to the product of the ratios of length, density, and gravity. With both the original and the model on the surface of the earth, however, g_2 and g_1 are the same so that $g_r = 1$. This reduces the strength ratio to

$$\frac{S_2}{S_1} = L_r \rho_r. \tag{10a}$$

Then if the density also is kept the same in both cases we obtain

$$\frac{S_2}{S_1} = L_r, \tag{10b}$$

which is the special result arrived at earlier by intuitive methods of reasoning.

Let us now employ these results to see if we can obtain some conception of what the aggregate strength of the earth may be. We have seen already that to stresses of a year or less the earth has a rigidity comparable with that of steel. Strength and rigidity are, however, not the same property, so we are not justified in supposing that the strength of the earth to short-period stresses is also the same as that of steel. In the light of available evidence a figure of the order of magnitude of the strength of surface rocks appears to be more probable. For purposes of illustration, however, let us be liberal in our assumptions; why not assume that the earth does have the strength of steel? Or to formulate the problem in a slightly different manner, let us consider a steel ball the size of the earth and then investigate what its aggregate strength would be.

We conceive of such a sphere resting on a horizontal surface in a uniform gravity field of the same intensity as that at the surface of the present earth. Small steel balls, as bearings, support loads thousands of times their own weight;

how large a load would this one be able to support? Small ball bearings bounce when dropped upon an anvil; would one this size be able to bounce also?

Taking the static problem first, we make use of the results of equation 10 and imagine this ball bearing the size of the earth to be reduced to laboratory size while maintaining physical similarity. We have already supposed gravity to be the same in both cases, and it will be convenient to keep the density the same. The earth has a radius of 6.37×10^8 cm. A convenient laboratory size would be a sphere with a radius of 63.7 cm., or about 2 feet. The strength ratio would then be

$$\frac{S_2}{S_1} = L_r = 10^{-7},$$

and if a value of 300,000 lb./in.^{2}, corresponding to strong alloy steel, be assumed for the original, then

$$S_2 = 3 \times 10^5 \times 10^{-7} = 0.03 \text{ lb./in.}^2,$$

or about 2.1 gms. (wt.)/cm.^{2}, would be the strength of the reduced sphere.

We should then have for our laboratory model a sphere of about 4 feet in diameter with the density of steel and a weight of about 9 tons. The strength of its material, however, would be but 0.03 lb./in.^{2} which would be comparable to that of toothpaste or soft mud. Hence such a sphere would not bounce; it would collapse and flow outward under its own weight.

If we repeat this argument for the actual earth, assuming a strength of 30,000 lbs./in.^{2}, the result we obtain is a sphere the same size as before with a mass almost as great, but only one tenth as strong.

VISCOSITY OF THE EARTH

It will be recalled that when the evidences of the rigidity of the earth were being reviewed, in each instance the observed rigidity was in response to stresses of comparatively brief duration. We now direct our attention to the behavior of the earth in response to stresses of much longer duration. The best example we have on record of the application and removal of such a stress on a large scale with relatively little complication by extraneous tectonic phenomena is to be found in the loading and unloading of the northern parts of the continents of both North America and Europe by the Pleistocene ice sheets.

Figure 2, which is reproduced from one of the drawings of Frank B. Taylor,[10] represents a southwest-northeast profile east of Lake Michigan from a point about a third of its length from its north end to a little north of Sault Ste. Marie, a distance of 160 miles. The vertical coordinate represents elevation above sea-level, and the series of curved profiles represents old beach ridges formed when the present Great Lakes were obstructed by ice at the north, forming the glacial lakes Algonquin and Nipissing.

[10] Frank Leverett and Frank B. Taylor, "The Pleistocene of Indiana and Michigan and the History of the Great Lakes," *Monographs U.S. Geol. Survey*, Vol. 53 (1915), opp. p. 430.

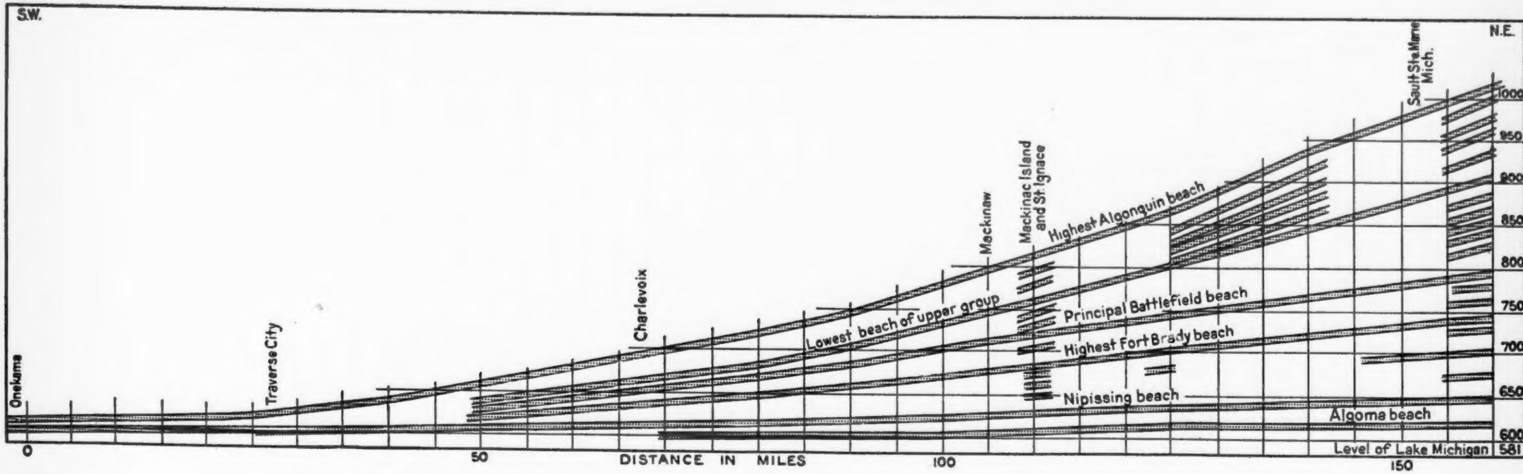

FIG. 2.—Beach profiles of glacial Lakes Algonquin and Nipissing showing post-glacial uplift (after Frank B. Taylor).

Two characteristics of these old beaches are outstanding: (1) with respect to a rectilinear base they are all concave upward with elevations increasing northward, and (2) they converge almost to coincidence on the southwest and diverge in a continuous manner northeastward. Since the surface of a lake can depart but slightly from level, it is clear that at the time the uppermost beach was formed this must have been substantially level, and between this time and that when the lowermost beach was formed, the land at the north end of the profile must have risen about 400 feet with respect to that at the south end.

The second lowest beach shown is that of the Nipissing stage. It represents a distinctly new level produced by the opening of a lower outlet, with a drop of the water level, as seen at the south end of the profile, by about 10 feet. The series of converging beaches between this and the highest Algonquin beach represents beaches that were formed while the tilting was taking place.

Profiles of this kind made by Taylor throughout the Great Lakes region all show consistently the same kind of behavior, namely, that the earth under the load of the ice sheet had evidently been pressed down, and as the ice sheet melted away the earth was slowly creeping back to its former level.

The time interval represented by the beaches of Figure 2 was but a part of the total time of the ice retreat. Other profiles of earlier stages indicate that 100 feet or more of uplift had already occurred in this area; furthermore, work in Canada shows a continuation of the highest Algonquin beach to a present elevation of 1,500 feet above sea-level. Thus the total differential uplift was probably not less than 900 feet.

This differential uplift is still taking place at a very much reduced rate. The northern end of Lake Michigan is still rising with respect to the southern end at a rate of about 1 foot per 100 miles per 100 years, and the greatest rate of present uplift of about 6 feet per 100 years is observed in the southern end of Hudson Bay.

Figure 3, which is based on the cumulative work of Scandinavian geologists,[11] shows the corresponding phenomenon for northern Europe. In this instance the last ice sheet covered Fennoscandia, and as it melted an uplift very like that in North America ensued. Marine waters in the Baltic region flooded areas which now stand at a maximum of about 275 meters (about 900 feet) above sea-level. Here also the uplift is still proceeding. In the northern part of the Baltic Sea the rate is about 11 millimeters per year (about 3.6 feet per 100 years).

The coincidence between these two areas and epochs of uplift with the unloading due to the melting of glacial ice is so impressive that there can scarcely be a doubt as to the direct cause-and-effect relationship, yet at the time when Taylor wrote his great work (published in the year 1915) he was sorely beset by the limitations imposed by the rigidity of the earth and was not entirely certain in his own mind that such a yielding of the earth under a load of this magnitude was

[11] Fridtjof Nansen, *The Earth's Crust, its Surface, Forms, and Isostatic Adjustment* (1928), Oslo.

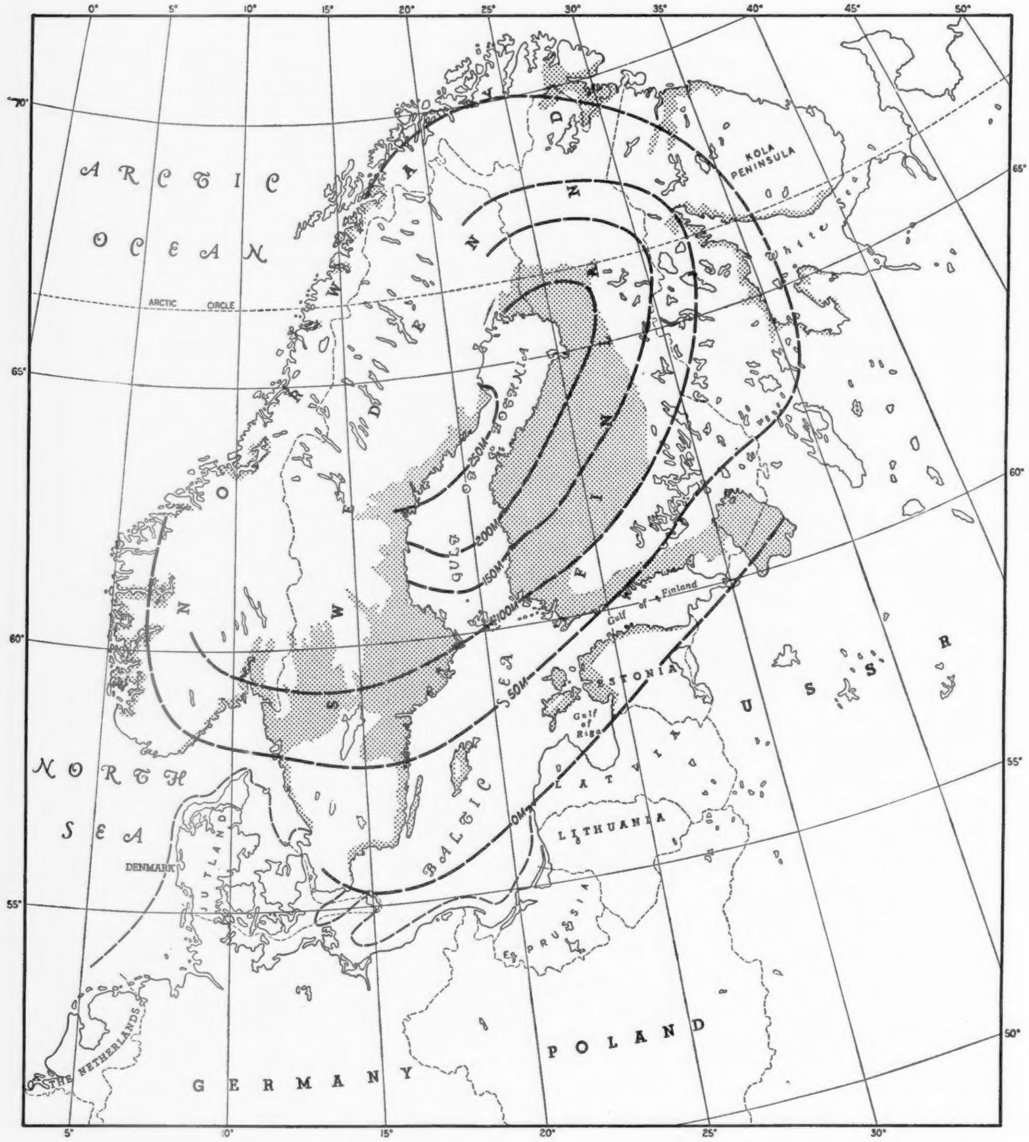

FIG. 3.—Post-glacial uplift in Scandinavia. Shaded areas show extent of sea following ice retreat.

possible. The conflicts with which he was obliged to deal are clearly set forth in the following passage.

Although the hypothesis of resilience following depression by ice weight appears to have much strength, perhaps this strength seems greater than it really is, because the phenomena contemplated are confined to a somewhat restricted field. Beyond the region of the Great Lakes a vast stretch of the earth's surface . . . [the whole of northeastern North America] . . . was affected at the same time and in the same way as the Great Lakes region. The very vastness of this area operates to exclude certain hypotheses that have been suggested. The limitations which it imposes seem particularly applicable to all hypotheses that depend on the transfer of subcrustal molten magmas, unless the modern conception of an essentially solid, rigid interior of the earth is wrong, and the old idea of a molten, highly fluid, essentially non-viscous interior, moving under hydrostatic laws, is right. The writer is disposed to accept the newer view. But this would exclude the transfer of molten magmas as a cause of resilience and place the whole burden on elasticity, which is calculated to account at most for less than two-fifths of the total uplift. Moreover, the failure of the uplifts to act instantaneously or pari passu with the removal of the ice weight casts a further doubt upon the relation of the uplifts to elasticity.[12]

Let us accept the hypothesis that these depressions and uplifts are indeed, as they appear to be, the direct consequence of the loading and unloading of the glacial ice. What information does this give us concerning the properties of the earth? It would appear that to stresses sustained over periods of thousands of years the earth yields by a viscous-like flowage in a manner somewhat similar to the yielding of asphalt or tar. When loaded it is slowly depressed and when the load is removed the stresses are reversed and it slowly creeps back to its former position of equilibrium.

But how may this be reconciled with the evidences of great rigidity? As is well known, there are many substances (sealing wax is the classic example) which respond elastically to short-term stresses, but which flow viscously under the influence of stresses of longer duration. To this property of being both elastically rigid, and viscous, Clerk Maxwell applied the apt name *elastico-viscosity*, and all our available evidence indicates that it is a property possessed by the earth. To stresses of a few years duration, the response of the earth is that of an elastically rigid solid; to stresses of thousands of years duration it resembles that of a highly viscous fluid.

So far as the present discussion is concerned it does not particularly matter whether this fluidity is real in the sense of that of an ordinary liquid, or apparent like the motion of a glacier. All that concerns us is that the response of the earth to loading and unloading is very much *as if* it were a highly viscous fluid, and it becomes a matter of first importance that we obtain some idea of the magnitude of its apparent coefficient of viscosity.

For this purpose two avenues of approach are open to us. We may make a frontal attack and from the size of the areas involved, the amount of the depression, and the time-rate of the uplift, we may by the employment of the equations of hydrodynamics attempt to derive the coefficient of viscosity directly. Or, by

[12] Frank B. Taylor, *op. cit.*, p. 516.

means of the principles of physical similarity we may reduce the problem to an equivalent one of laboratory scale and obtain the viscosity of the earth by direct measurement.

Adopting the second of these procedures, we imagine one of the areas of post-glacial uplift to be reduced to a convenient laboratory scale while maintaining physical similarity. Since the motion considered is one of slow creep the forces due to inertia are negligible compared with the other forces which act, so that we are no longer bound by the usual restriction of mechanics whereby force is determined by mass, length and time. In fact, for a problem of this kind, we have *four* independent mechanical quantities instead of the usual three. For these we could choose mass, length, time, and force, but it will be somewhat more convenient if we select length, density, time, and gravity as our fundamental quantities. In terms of these our fundamental scale ratios will then be:

Quantity	*Scale Ratio*
Length	$\dfrac{l_2}{l_1} = L_r$
Density	$\dfrac{\rho_2}{\rho_1} = \rho_r$
Time	$\dfrac{t_2}{t_1} = T_r$
Gravity	$\dfrac{g_2}{g_1} = g_r$

Here, as previously, the subscript 1 refers to the original and 2 to the replica.

In the case of the post-glacial uplift the length, density, time and gravity are all known to a fair degree of accuracy. Choice of the corresponding quantities for the reduced version then determines the fundamental scale ratios L_r, ρ_r, T_r and g_r. These choices are arbitrary with the exceptions that the motion must always be slow enough that inertial forces may be neglected, and that on the earth $g_2 = g_1$ or $g_r = 1$.

In terms of the foregoing quantities taken as fundamental the ratio of the viscosity of the reduced version to that of the original must be

$$\frac{(\text{Viscosity})_2}{(\text{Viscosity})_1} = \frac{\mu_2}{\mu_1} = \frac{(\text{Stress})_2 \times (\text{Time})_2}{(\text{Stress})_1 \times (\text{Time})_1}$$

$$\frac{\dfrac{(\text{Force})_2 \times (\text{Time})_2}{(\text{Area})_2}}{\dfrac{(\text{Force})_1 \times (\text{Time})_1}{(\text{Area})_1}} = \frac{\dfrac{g_2\rho_2 V_2 t_2}{A_2}}{\dfrac{g_1\rho_1 V_1 t_1}{A_1}} = \frac{l_2}{l_1}\cdot\frac{\rho_2}{\rho_1}\cdot\frac{t_2}{t_1}\cdot\frac{g_2}{g_1}, \tag{11}$$

where V signifies volume. Then

$$\mu_r = L_r\rho_r T_r g_r, \tag{12}$$

which, since $g_r = 1$, simplifies further to

$$\mu_r = L_r\rho_r T_r. \tag{13}$$

This tells us that the ratio of the viscosities is equal to the product of the ratios of length, density and time.

To determine μ_1, the viscosity of the earth, all we need to do is to assign values for L_r, ρ_r, and T_r, and construct a model according to those specifications. The earth viscosity will then be

$$\mu_1 = \frac{\mu_2}{\mu_r} = \frac{\mu_2}{L_r\rho_r T_r}. \tag{14}$$

Without actually performing this experiment, equation 14 enables us to obtain an idea of the approximate order of magnitude of μ_1. Consider the post-glacial uplift in Scandinavia whose parameters are somewhat more accurately known than those for the uplift in North America. The radius of the depressed area is about 1,000 kilometers (10^8 cm.), the average density of the rocks involved is about 3.5 gm./cm.^{3} and the time for the uplift to equal one-half the initial depression is about 10,000 years or 3×10^{11} seconds. For the reduced version a convenient scale would be a radius for the depressed area of 10 centimeters, a density of 1.4 gm./cm.^{3}, and a time constant for the uplift to equal half the depression of 10 minutes. The numerical values of the fundamental scale ratios would then be

$$L_r = \frac{10}{10^8} = 10^{-7},$$

$$\rho_r = \frac{1.4}{3.5} = 0.40,$$

$$T_r = \frac{6\times 10^2}{3\times 10^{11}} = 2\times 10^{-9}.$$

When these numerical values are substituted into equation 14,

$$\mu_1 = (1.25\times 10^{16})\mu_2, \tag{15}$$

so that it remains only to estimate what the viscosity of a liquid would have to be in order for a shallow depression of 10 centimeter radius to have a recovery time constant of 10 minutes.

The required viscosity obviously lies between that of ordinary viscous liquids like honey, and the highly viscous ones such as asphalt. The time constant for honey with a viscosity of 40 poises would probably be of the order of a tenth of a second, whereas that of asphalt at room temperature would be of the order of a

day. An intermediate liquid is waterglass. A viscous solution of waterglass still sufficiently fluid to be stirred by hand will recover from a depression of this size at a visible rate, with a recovery constant of the order of tens of seconds. What is sought, therefore, is evidently a liquid with a viscosity intermediate between that of the waterglass referred to, and asphalt. The viscosity of the waterglass is about 10^4 poises and an average value for that of asphalt at 77°F. is about 6×10^6 poises. The required value, therefore, should be of the order of 10^5 to 10^6 poises.

Inserting these values into equation 15 then gives as an order of magnitude for the viscosity of the earth

$$\mu_1 \cong 10^{21} \text{ to } 10^{22} \text{ poises}, \tag{16}$$

which is in good agreement with the figure of about 10^{22} poises obtained by various investigators by direct calculation.

In the flow systems under consideration the deformation extends to great depths—probably several hundred miles—so that the viscosity determined is approximately an average or effective value for the aggregate of the materials involved. In the depressed areas of both North America and Europe the surface rocks are those of the great pre-Cambrian shields and are representative of the strongest rocks on earth. Does this figure of 10^{22} poises characterize these surface rocks also, or does it apply only to a more fluid substratum upon which the surface rocks repose as a semi-rigid "crust"? If the surface rocks had a viscosity of this amount, and negligible strength, topographic eminences would tend to be obliterated by flowage, but would the rate of flow be great enough to produce visible distortion before these same features were erased by the processes of erosion?

For the light that it may shed upon these and kindred problems it will be instructive to inquire what a viscosity of 10^{22} poises means. Suppose one were given a hand specimen of material with this property; how would its behavior differ from materials ordinarily regarded as rigid? A viscous body will undergo deformation indefinitely by flowage under the action of differential, or shear stresses, and the simplest way to apply such a stress is by uniaxial tension or compression of a cylindrical or prismatic specimen. The rate of flow in such an instance, as given by the equations of hydrodynamics, will be

$$\frac{\partial w}{\partial z} = \frac{\sigma_z}{3\mu}, \tag{17}$$

where σ_z is the stress applied parallel to the z-axis (positive if tensile, negative if compressive), μ is the viscosity and w the velocity parallel to the z-axis. Regarding the origin as fixed at one end of the specimen, and integrating, the velocity at any distance z along the specimen will be

$$w = \int \frac{\partial w}{\partial z}\, dz = \frac{\sigma_z}{3\mu} z. \tag{18}$$

In time dt the particle at distance z will be displaced by the amount

$$dz = wdt = \frac{\sigma_z}{3\mu} zdt,$$

and the proportional elongation or strain of the specimen will be

$$\frac{dz}{z} = \frac{\sigma_z}{3\mu} dt. \tag{18a}$$

Then, integrating equation (18 a),

$$\ln \frac{z}{z_0} = \frac{\sigma_z t}{3\mu}, \tag{19}$$

or

$$\frac{z}{z_0} = e^{\sigma_z t/3\mu}, \tag{20}$$

which is the ratio of the final to the initial length of the specimen after a time t.

In the case of the surface rocks of the earth the greatest stress differences arising from other than tectonic causes are those associated with extreme topographic relief. These reach their maximum values at the bases of vertical cliffs where the maximum principal stress is equal to the pressure of the rocks above and the other two principal stresses are near zero. A value representative of the larger of such stress differences would be

$$\sigma_{\max} - \sigma_{\min} = 10^8 \text{ dynes/cm.}^2,$$

which is approximately the differential stress acting upon the rocks at the foot of a vertical cliff 1,200 feet (370 meters) high. What would be the shortening of the rocks at the base of such a cliff if they flowed with a viscosity of 10^{22} poises? About the least shortening that can be readily detected by precise physical measurement would be one part per million, and the least that would be noticeable geologically would be of the order of one part in ten. How long would it take for the specimen under a uniaxial compression of 10^8 dynes/cm.^{2} to shorten by the amounts, respectively, of one part per million and one part in ten?

The answers to these questions are provided by solving equation 19 for t and introducing the appropriate numerical data. Solving for t gives

$$t = \frac{3\mu}{\sigma_z} \ln \frac{z}{z_0} \cdot$$

For a shortening of one part per million

$$t = \frac{3 \times 10^{22}}{-10^8} \ln (1 - 10^{-6}) = 3 \times 10^8 \text{ seconds}$$
$$= 10 \text{ years.}$$

For a shortening of one part in ten, the time required will be

$$t = \frac{3 \times 10^{22}}{-10^8} \ln (1 - 0.1) = 3 \times 10^{13} \text{ seconds}$$
$$= 1 \text{ million years.}$$

Thus if the surface rocks of the earth had a viscosity of 10^{22} poises, under the sustained loading of extreme mountain topography the viscous flowage in localities of greatest stress would become barely perceptible in a period of one million years. Since, however, extreme mountain topography is the most subject of all topography to rapid denudation by erosion there are grounds to doubt whether any such topographic features would persist long enough for the resultant cumulative creep to become evident. Therefore it is difficult to say definitely at the present time that the surface rocks of the earth are either more rigid or less fluid than a material having a viscosity of 10^{22} poises.

If on the basis of fragmentary evidence we conclude that the crystalline rocks at and near the earth's surface are more rigid then this we still are left with slight information concerning the rapidity with which this surface strength and rigidity diminishes with depth. What is most important, however, is the fact that a viscosity of 10^{22} poises, which appears to be an average characteristic of the earth materials to great depths, implies a material whose general physical properties differ but slightly from those of the surface rocks of the earth.

Having arrived at this general conclusion, it will be instructive to compare the behavior in geologic time of tens of millions of years of an earth having this general property with the short-time behavior of materials with which we are familiar. As before, let us imagine the earth to be reduced both in size and in time to a convenient laboratory scale. For size a convenient reduction would be 1 to 10 million, and for time a suitable value would be 1 minute to 10 million years. The density could be reduced by about 1 to 2, and gravity left the same. This would give for our fundamental reduction ratios:

$$L_r = 10^{-7}$$
$$T_r = 2 \times 10^{-13}$$
$$\rho_r = 0.5$$
$$g_r = 1.0.$$

The reduction ratio of viscosity is then obtained by introducing these values into equation 12:

$$\mu_r = \frac{\mu_2}{\mu_1} = 10^{-7} \times 2 \times 10^{-13} \times 0.5 \times 1.0$$
$$= 10^{-20},$$

from which the value of the reduced viscosity is found to be

$$\mu_2 = \mu_1 \times 10^{-20} = 10^{22} \times 10^{-20} = 100 \text{ poises.}$$

If we also assume that the surface rocks have finite strength to long sustained stresses, the strength for the reduced system would be obtained in the same manner as heretofore. By equation 10,

$$S_r = \frac{S_2}{S_1} = L_r \rho_r g_r,$$

and when the preceding values of the reduction ratios are employed,

$$\frac{S_2}{S_1} = 10^{-7} \times 0.5 \times 1.0 = 5 \times 10^{-8}.$$

Then if we assume a strength of about 30,000 lbs./in.^{2} or 2×10^9 dynes/cm.^{2} the reduced strength would be

$$S_2 = (5 \times 10^{-8}) S_1$$
$$= 1.5 \times 10^{-3} \text{ lbs./in.}^2, \text{ or } 10^2 \text{ dynes/cm}^2.$$

A viscosity of 100 poises is only about two to three times that of honey; a strength of 0.0015 lb./in.^{2} is comparable with that of very soft mud or pancake batter. Since the method of reduction employed has been such that the original and its reduced replica must behave in a physically similar manner, we are led to a remarkable conclusion—that *without the necessity of any special hypotheses of strength much less than, or of fluidity much greater than, that of the crystalline rocks of the earth's surface, the behavior of the earth as a whole in geologic time must be very similar to that of the ordinary viscous fluids and extremely soft muds of our everyday experience.*

EXPERIMENTAL CONFIRMATION

Although results of this kind may appear somewhat startling they are not without ample experimental confirmation. For more than a century and a quarter attempts have been made to simulate the formation of mountains and other tectonic structures by means of small scale models. In the preponderance of such cases the materials used have consisted of hard waxes, stiff clays, partially cemented sands, plaster of Paris and similar substances, and the results have been indifferent at best. Typical and among the better known of such experiments are those made by Bailey Willis[13] in his classical study of the folding of the Appalachian Mountains. Willis constructed models of about a meter in initial length representing the unfolded strata of the Appalachian geosyncline. These were compressed longitudinally into structures simulating those of the Appalachian Mountains.

The basic material used in these experiments was beeswax. Strata of greater rigidity were produced by the addition of plaster of Paris, while weaker strata

[13] Bailey Willis, "The Mechanics of Appalachian Structure," *U. S. Geol. Survey 13th Ann. Rept.*, Pt. 2 (1891–1892), pp. 211–89.

were obtained by cutting the beeswax with Venice turpentine. Willis found it necessary to cover his models during their deformation with an overburden of lead shot to a depth of 20 to 40 centimeters producing pressures up to 5.5 lbs./in.^{2}, in order to hold them down.

If one of Willis' models were to be regarded as representing an Appalachian section of about 100 kilometers in length the overburden used would be equivalent to 150 to 300 kilometers of rock. Even then the more rigid strata broke into discrete slabs and open cavities appeared. The Appalachians had no such overburden, but were held down solely by their own weight, yet the folding in the most rigid strata was continuous and no open cavities were formed. Hence it must be concluded that the rocks of the Appalachians in respect to their environment were much weaker than the materials used by Willis, or conversely, that Willis' materials were much too strong to represent the Appalachian Mountains.

As remarked before, the materials used and the results obtained by Willis are typical of most of the model experiments upon geologic structures which have so far been performed. Notable exceptions occur in the cases of some experiments performed by Koenigsberger and Morath[14] about 1912, and in the later 1920's by Hans Cloos.[15] The proper strength for model materials was correctly deduced by Koenigsberger and Morath but their efforts were handicapped by an unfortunate choice of the experimental materials. Cloos reasoned simply that if an original geologic feature were composed of rocks strong enough to support a column 10 to 20 kilometers high, a model with a length reduction of 1/50,000 should be composed of material capable of supporting a column 1/50,000 as high, or 20 to 40 centimeters. On this basis he then selected soft, half-liquid clay as his experimental material. With this he has been able to obtain some of the most accurate duplications of a wide variety of geologic structures which have so far been achieved.

Better known to the oil fraternity are the experiments of Nettleton[16] wherein salt-dome formation has been represented by means of viscous fluids of contrasting densities. While not accurate in all details, these experiments of Nettleton afforded a far more convincing demonstration of the mechanics of salt-dome formation than any previous attempts.

Recently a model experiment has been described by Griggs[17] for the demonstration of the hypothesis of mountain folding by deep-seated convection. The

[14] G. Koenigsberger and O. Morath, "Theoretische Grundlagen der Experimentallen Tektonik," *Zeitschrift der Deutschen Geologischen Gesellschaft*, Vol. 65 (1913), pp. 65–86.

[15] Hans Cloos, "Kunstliche Gebirge," *Nat. u. Mus. Senckenbergische Naturforschende Gesellschaft*, Pt. 1 (Frankfort, 1929), pp. 225–43; Pt. 2 (1930), pp. 258–69.

[16] L. L. Nettleton, "Fluid Mechanics of Salt Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), pp. 1175–1204.

———, "Recent Experimental and Geophysical Evidence of Mechanics of Salt-Dome Formation," *ibid.*, Vol. 27, No. 1 (1943), pp. 51–63.

[17] David Griggs, "A Theory of Mountain-Building," *Amer. Jour. Sci.*, Vol. 239 (1939), pp. 611–50.

model parameters of that experiment were determined in accordance with the theory as developed by the present writer. The results were in remarkable accord with the major tectonic features of many existing mountain ranges.

IMPLICATIONS TO GEOLOGIC THINKING

The implications of these facts to geologic thinking are far-reaching. It now becomes manifest that much of the conflict reviewed at the outset of the present paper between the evidences of rigidity and those of fluidity was not a conflict of data but of thinking. Our direct experiences with features of the surface of the earth are unavoidably limited to quantities whose magnitudes are commensurate with those of the human body—lengths of a few meters, times of a few years, forces of a few tens of pounds, *et cetera.* In such terms, the crystalline rocks of the earth appear infinitely rigid and enormously strong. In considering these same rocks on a length scale of hundreds or thousands of miles and a time scale of tens of millions of years we have no means of anticipating their behavior except by analysis, yet without making such an analysis we have become accustomed unwittingly to substituting our small-scale experiences into our thinking about large-scale phenomena. When we think of an earth having the rigidity of steel we are prone to substitute our personal knowledge of small steel balls; when we think of an earth whose surface is composed of the strong and rigid crystalline rocks of our small-scale observation we tend to endow the earth as a whole with the same properties and the geological evidences of great weakness become difficult of comprehension.

It is only when we analyze the expected behavior of such materials on a scale of geologic space and time and translate these results into terms within the domain of human experience that we realize how enormously wrong we have been. We learn that the resemblance of the behavior of rocks on a length scale of thousands of miles and a time scale of millions of years is not to that of the rocks with which we are familiar but rather to that of the viscous liquids and weaker plastics of our personal experience.

In view of this, the gulf which heretofore has divided geologic thinking into such extremes as the "hard-rock theory" and the "soup theory" no longer seems so impassible. It now appears, in fact, that in geologic space and time the behavior of an earth built to the specifications of the staunchest adherents of the hard-rock school would leave little to be desired by the most incorrigible apostles of fluidity.

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GEOLOGICAL NOTES

ROSICLARE-FREDONIA CONTACT IN AND ADJACENT TO HARDIN AND POPE COUNTIES, ILLINOIS[1]

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The presence of a possible unconformity at the top of the Fredonia limestone, which is the lowest member of the Ste. Genevieve formation of the Mississippian system, has been recognized by a number of geologists in the past few years. At a meeting of petroleum geologists in Mattoon, Illinois, in February, 1938, L. E. Workman[3] presented data indicating an unconformity involving structural deformation and erosion at the base of the Rosiclare sandstone in the Clay City-Noble area of Clay and Richland counties. He pointed out that the Rosiclare sandstone thins over structures and that the interval between its base and the top of a distinctly sandy zone in the Fredonia varies considerably, and also suggested that "on consideration of lithology only . . . the base of the Rosiclare sandstone . . . might well be considered the base of the Chester series." In his study of the Iowa (Lower Mississippian) series, J. N. Payne[4] recognized the same features noted by Workman two years earlier and also called attention to an apparent overlap of Rosiclare sandstone on the underlying Fredonia limestone along the margins of the Illinois basin and the existence of areas of channel-like thinning of the Fredonia limestone in southwestern Illinois.

Recent studies by the writer, including the examination of many diamond-drill cores obtained in testing for fluorspar, in extreme southern Illinois and in the neighboring part of Kentucky have furnished new evidence bearing upon the stratigraphic relations of the upper part of the Ste. Genevieve limestone as that formation is currently recognized. Some disagreement exists among members of the Illinois State Geological Survey regarding the significance of this evidence, so that the writer's conclusions have not been adopted as official by the Survey. However, the data obtained by the writer and his interpretations are presented here because they have an important bearing on, and may stimulate further consideration of, the problem.

The Ste. Genevieve formation is overlain by the Renault formation in Hardin and Pope counties. In southwestern Illinois the Aux Vases sandstone intervenes

[1] Manuscript received, March, 1945. Published with permission of the chief of the Illinois State Geological Survey, Urbana, Illinois. Read before the Illinois State Academy of Science, DeKalb Meeting, May, 1944.

[2] Subsurface Geology Division, Illinois State Geological Survey.

[3] L. E. Workman, "Subsurface Stratigraphy of Cypress to Fredonia Formations in the Illinois Basin," with discussions by Lynn K. Lee and Robert G. Kurtz (February 4, 1938, mimeographed).

[4] J. Norman Payne, "Subsurface Geology of the Iowa (Lower Mississippian) Series in Illinois," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), p. 129; *Illinois Geol. Survey Rept. Inv. 61* (1940).

between the Ste. Genevieve and Renault formations, but according to the writer's interpretations, it is not present east of western Johnson County, as shown in the cross section *BB′* (Fig. 3). Throughout the area covered by this report, the Renault formation may be subdivided on the basis of insoluble residues into five persistent zones,[5] as follows.

Zone	*Average Thickness (Feet)*
E. Cherty limestone, characterized by silicified fossils, 5 to 27% insoluble	25
D. Coarsely silty limestone, total residue 8 to 15%, 6 to 10% consisting of coarse silt grains	10
C. Finely silty shales with few limestone lenses, 75 to 80% insoluble	20
B. Relatively pure limestone, average residue about 9%, coarse insoluble portion characterized by fine acicular quartz crystals and very fine tubular silt aggregates comprising 1 to 4% of total rock	13
A. Argillaceous, coarsely silty limestone, total residue content 10 to 58%, 5 to 15% consisting of coarse silt grains	14

In and adjacent to Hardin and Pope counties, Illinois, the Ste. Genevieve formation is divided into three members, the Levias limestone above, the Rosiclare sandstone, and the Fredonia limestone below.

The Levias limestone is readily separable from zone A of the Renault formation by an abrupt change in total residue content in that the Levias averages less than 7 per cent insoluble and the coarse fraction, characterized by very fine silt aggregates, rarely exceeds one per cent of the total rock. The Levias is typically light buff coarse very oölitic limestone containing coarse pink crinoid fragments and becoming sandy in the lower part. The upper few feet are generally buff to light brown more or less oölitic limestone. In most places, the contact between the Levias limestone and the Rosiclare sandstone is gradational, the lower 3 to 5 feet of Levias being more or less sandy. However, in a few diamond-drill cores in Hardin County, a thin conglomerate has been noted in the basal Levias.

The Rosiclare, as typically developed in the area studied, is a very calcareous coarse siltstone grading both laterally and vertically to very fine sandstone or very sandy or silty limestone. The average calcium carbonate content of the Rosiclare member is about 40 per cent and may run as high as 75 per cent. Conglomerates are very common in the middle and lower parts of the Rosiclare. These conglomerates have been recorded in study of cores and of geologic sections encountered in shafts in Hardin County. In the Cave in Rock district the basal Rosiclare is, in many places, characterized by green very silty calcareous shale. The contact with the underlying Fredonia is everywhere, so far as known, sharp with an abrupt change from the high silt content of the Rosiclare to the very pure oölitic limestone of the upper Fredonia.

The Fredonia member of the Ste. Genevieve formation, as currently recognized, is readily divisible into three units, an upper limestone, a middle sandstone, and a lower limestone.

[5] F. E. Tippie, "Insoluble Residues of the Levias and Renault Formations in Hardin County, Illinois," *Trans. Illinois State Acad. Sci.*, Vol. 36 (1943), pp. 155–57.

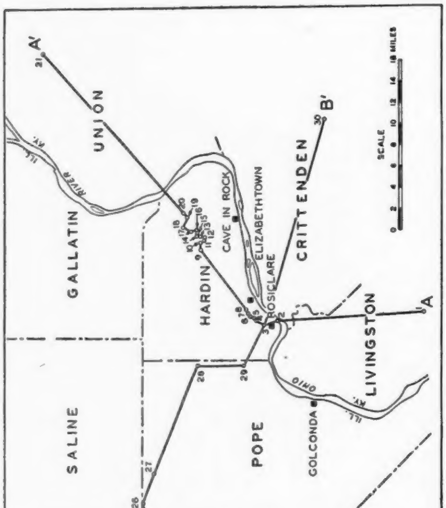


FIG. 1.—Index map showing lines of cross sections.

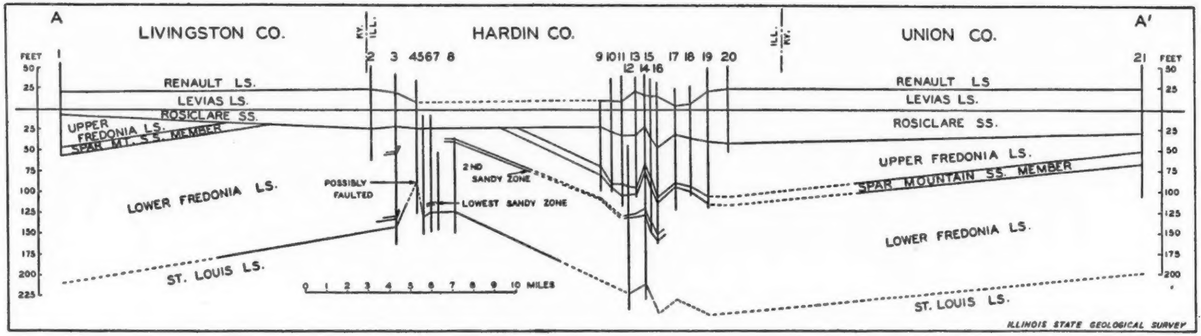


FIG. 2.—Geologic cross section AA' of Ste. Genevieve strata.

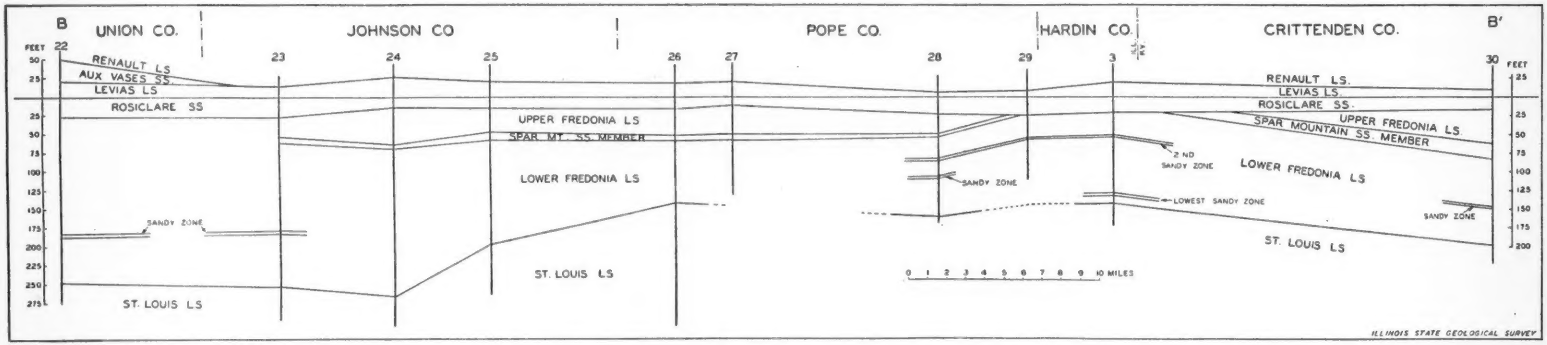


FIG. 3.—Geologic cross section BB' of Ste. Genevieve strata.

The upper Fredonia is a relatively pure limestone with no silty or sandy zones, shaly zones being developed only locally. The contact of the upper Fredonia and the underlying sandstone is a distinct break from limestone above that is non-sandy, non-glauconitic, generally non-oölitic, brown, and very fine-grained, to limestone below that is sandy, glauconitic, oölitic, light gray to greenish, becoming increasingly sandy downward. This break is generally marked in cores by a dark brown shale parting which in many places exceeds ½ inch in thickness. The contact shows unconformity as recognized by the writer at Barrett's quarry on Bissell Bluff, Livingston County, Kentucky.

The middle sandstone member has heretofore been known as a "sub-Rosiclare sandstone."[6] It is here proposed to designate this as the "Spar Mountain sandstone," being so named because it crops out on the south slope of Spar Mountain in Secs. 3 and 4, T. 12 S., R. 9 E., Hardin County, about 4 miles northwest of Cave in Rock. It is typically developed at this place as a light gray to greenish calcareous glauconitic sandstone or siltstone grading to very sandy limestone. The best exposure seen by the writer is in the Oxford open-cut in the NE. ¼ Sec. 4, on property formerly owned and operated by the Benzon Fluorspar Company. It varies in thickness from 8 to 15 feet. There is everywhere a sharp break from the Spar Mountain sandstone to the characteristic non-sandy lower Fredonia limestone.

The lower Fredonia is in general a white to light brown relatively pure and more or less oölitic limestone. In many places it is petroliferous. As shown in the cross sections (Figs. 2, 3) it contains at least two thin sandy zones that rarely exceed 2 or 3 feet in thickness, in contrast to the Spar Mountain sandstone which is rarely less than 8 feet thick. A sandy zone about 30 to 40 feet below the Spar Mountain seems to be traceable throughout most of Hardin County, although it was not recognized in some cores in the Rosiclare district. The lower Fredonia limestone is about 125 feet thick and is underlain by the St. Louis limestone. The basal contact is characterized by coarse buff to light brown oölitic or partly crystalline, partly sandy or silty, non-cherty limestone resting on dark brown lithographic to very fine-grained cherty dolomitic limestone of the St. Louis formation.

In the vicinity of Spar Mountain the interval between the base of the Rosiclare sandstone and the top of the Spar Mountain sandstone varies from 55 to 67 feet. Locally the interval is considerably less, but this condition is thought by the writer to be correlative with the presence of fluorspar ore in the upper Fredonia limestone and the thinning of the latter by solution during mineralization and therefore not a depositional feature. The Spar Mountain sandstone in this area averages about 10 feet in thickness and the underlying lower Fredonia limestone is about 120 feet thick.

Ten miles southwest of Spar Mountain, in the vicinity of Rosiclare, the entire thickness of Fredonia limestone averages about 115 feet. Here the upper Fre-

[6] Stuart Weller and others, "Geology of Hardin County," *Illinois Geol. Survey Bull. 41* (1920), p. 109.

donia limestone and the Spar Mountain sandstone seem to be entirely absent, and the Rosiclare sandstone is believed to rest directly on the lower Fredonia limestone. If this interpretation is correct, the magnitude of the unconformity below the Rosiclare sandstone is at least 75 feet.

Seven miles northwest of Rosiclare, in the vicinity of the Empire Mining district in eastern Pope County (test hole 28 on cross section *BB′*), the interval from the base of the Rosiclare sandstone to the top of the Spar Mountain sandstone is but 25 feet. Farther west the interval ranges from 30 to 50 feet as far as Union County, where there are suggestions that the Rosiclare again rests on the

FIG. 4.—Rosiclare sandstone with 4½ feet of basal shaly part, on Fredonia limestone in Spar Mountain district, SW. 1/4, NE. 1/4, NW. 1/4 Sec. 3, T. 12 S., R. 9 E., Hardin County.

lower Fredonia. The Spar Mountain can be traced throughout Hardin, Pope, and Johnson counties except where the unconformity cuts it out entirely.

In the Spar Mountain district the thickness of the Rosiclare sandstone varies from 22 to 43 feet. The upper Fredonia limestone in this region commonly is correspondingly thinner wherever the Rosiclare is thicker. Variations of this nature occur within distances of only a few hundred feet, suggesting that there is an erosional unconformity between the two units and that where it is thickest the Rosiclare sandstone occupies channels cut in the surface of the upper Fredonia limestone.

Where the Rosiclare is locally thicker than average, the lower few feet consist of very shaly glauconitic siltstones. These are interpreted as having been de-

posited in topographic depressions as the Rosiclare sea encroached on the land and before complete inundation and widespread deposition of sandstone took place. Figure 4 shows such a well developed basal shaly zone above the Fredonia limestone and below the massive cross-bedded sandstone more typical of the Rosiclare in the Spar Mountain district.

The cross sections clearly exhibit evidence of pre-Rosiclare structural deformation in Hardin County. Whether this deformation is widespread or not has not yet been determined.

A polished section of a diamond-drill core from Spar Mountain (Fig. 5) shows the following features suggesting an unconformity at the Rosiclare-Fredonia contact: (1) the contact between the formations is sharp and irregular; (2) the upper inch of Fredonia limestone is slightly leached and of lighter color; (3) small discolored solution channels in the Fredonia stop abruptly at the base of the Rosiclare; (4) a thin layer of black clay, possibly residual after leaching of the Fredonia limestone, separates the two formations; and (5) the basal Rosiclare is a conglomerate consisting of pebbles of white oölitic limestone, typical of the Fredonia, in a matrix of greenish siltstone. The pebbles of oölitic limestone are leached and porous and are mostly subround though some are angular. Such conglomerates have been noticed by the writer in many diamond-drill cores of the Rosiclare. Conglomerates are relatively common throughout the middle and lower Rosiclare. Leaching of the Fredonia pebbles and of the upper beds of the Fredonia is significant, for such leaching could only take place under sub-aerial conditions.

In contrast to the evidences of considerable erosional unconformity at the base of the Rosiclare sandstone, the break between the Levias limestone and the overlying Chester series does not indicate a comparable unconformity in this region. The maximum thickness of Levias thus far reported in and adjacent to Hardin and Pope counties is 35 feet, and nowhere in these counties is it known to have been entirely removed by pre-Renault erosion.

In Barrett's quarry on Bissell Bluff, 4½ miles northeast of Smithland, Livingston County, Kentucky, where it is reported[7] that the Renault formation rests on Fredonia limestone, examination by the writer reveals at the eastern end of the quarry 6 feet of green shaly siltstone and sandy limestone, very similar in character to the basal Rosiclare. This zone is overlain unconformably by 22 feet of oölitic limestone, which the writer correlates as Levias, and is underlain unconformably by 39 feet of upper Fredonia limestone. The lower contact exhibits at least 3 feet of relief in the eastern half of the quarry. If these correlations are correct, a normal thickness of Levias is present and the amount of pre-Renault erosion here also is negligible.

At a locality in Crittenden County, Kentucky, about 4 miles northwest of Marion, it is reported[8] that Renault limestone rests on Rosiclare sandstone. The

[7] J. Marvin Weller and A. H. Sutton, "Mississippian Border of the Eastern Interior Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), p. 820; *Illinois Geol. Survey Rept. Inv. 62* (1940).

[8] J. Marvin Weller, and A. H. Sutton, *op. cit.*, p. 820.

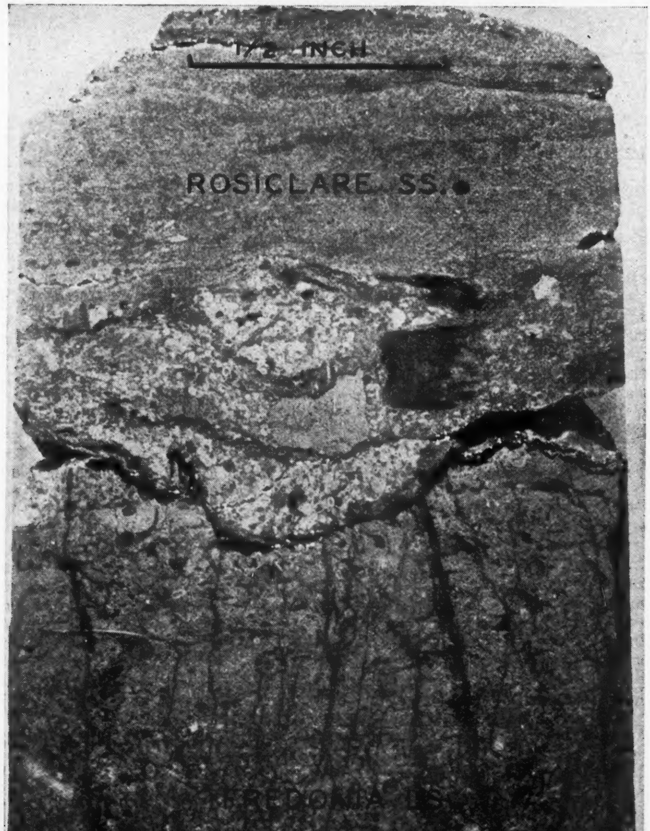


FIG. 5.—Contact of Rosiclare sandstone on Fredonia limestone in diamond-drill core from Spar Mountain district, SW. 1/4, SW. 1/4 Sec. 34, T. 11 S., R. 9 E., Hardin County.

RECORDS USED IN CROSS SECTIONS
(See Figures 2 and 3)

Map No.	*Company and No.*	*Quarter Section*	*Section*	*Township South*	*Range East*
	Livingston County, Kentucky				
1	Barrett's Quarry section, 18-I-14				
	Hardin County, Illinois				
2	Downey's Bluff section	NW SE	5	13	8
3	Rosiclare Lead and Fluorspar Mining Co.—D.D.H. Ac. 1	NE SW	32	12	8
4	Hillside Fluor Spar Mines—D.D.H. 107-D	NW SE	29	12	8
5	Rosiclare Lead and Fluorspar Mining Co.-D.D.H. Dc. 22	SE NE	29	12	8
6	Rosiclare Lead and Fluorspar Mining Co.—D.D.H. Ac. 14	NE NE	29	12	8
7	Rosiclare Lead and Fluorspar Mining Co.—D.D.H. Dc. 15	SW SW	21	12	8
8	R. S. Tems *et al.*—D.D.H No. 1	SE NE	21	12	8
9	R. S. Tems—D.D.H. No. 1	SW SE	33	11	9
10	Victory Fluorspar Mining Co.—D.D.H. No. 126	NE SE	33	11	9
11	Victory Fluorspar Mining Co.—D.D.H. No. 117	SW SW	34	11	9
12	U. S. Bureau of Mines—D.D.H. No. 25 (Victory)	SE SW	34	11	9
13	Victory—Crystal—D.D.H. No. 3	NE SW	34	11	9
14	Victory Fluorspar Co.—D.D.H. No. 55	SE NW	34	11	9
15	Century Zinc Co.—Wm. Davis No. 17	NW NE	34	11	9
16	Century Zinc Co.—A. L. Davis No. 1	NW NW	35	11	9
17	Mahoning Mining Co.—S. Joiner No. 1	SE NE	27	11	9
18	Mahoning Mining Co.—Hyman No. 4	SE SW	23	11	9
19	Mahoning Mining Co.—S. E. Oxford No. 3	SW NW	25	11	9
20	Minerva Oil Co.—Ledbetter No. 19	SE SE	24	11	9
	Union County, Kentucky				
21	Phillips—Kington Coal Co. No. 1, 1-0-19				
	Union County, Illinois				
22	Little Egypt Oil and Gas Co.—Bassler No. 1	SE SE	35	11	1 W.
	Johnson County, Illinois				
23	J. Zeppa—Albright No. 1	NW SE	22	12	2
24	Tunnell Hill Oil Co.—Boner No. 1	SW NE	30	11	3
25	Hiawatha Oil and Gas Co.—Cavitt No. 1	SW NW	24	11	3
	Pope County, Illinois				
26	Ohio Oil Co.—Hancock No. 1	NE NE	4	11	5
27	C. C. Whitlock *et al.*—Anthis No. 1	NW NE	12	11	5
28	U. S. Bureau of Mines—D.D.H. No. 34 (Empire Dist.)	NE NW	34	11	7
29	Thompson *et al.*—Anderson D.D.H. No. 1	SE NW	22	12	7
	Crittenden County, Kentucky				
30	Detrick—Orr No. 1, 24-K-19				

limestone overlying the Rosiclare was correlated with the Renault because no *Platycrinus penicillus* (Ste. Genevieve index fossil) was found; however, neither have any Renault index fossils been recognized in the lower part of this limestone.[9] Inasmuch as the total insoluble residue content of the lower portion of this limestone is very low and the coarse fraction contains fine silt aggregates, many of them tubular in shape, typical of the Levias in Hardin County, and the residue of the overlying beds check perfectly with zones A and B of the Renault,[10] the writer correlates the lowest 10 feet of limestone with the Levias. If this is correct, there is at this locality, also, no complete removal of the Levias limestone before Renault deposition.

[9] A. H. Sutton, personal communication.

[10] F. E. Tippie, *op. cit.*, pp. 155–57.

Thus, in and adjacent to Hardin and Pope counties, Illinois, the unconformity at the top of the Fredonia limestone is a more important break than is the one at the top of the Levias limestone. If this condition should be true for the whole Illinois basin, as the writer suspects it is from his studies of oil-well cuttings in the basin, it may develop that the base of the Rosiclare sandstone, rather than the base of the Aux Vases sandstone as now recognized, should be considered the base of the Chester series of alternating thin sandstone and limestone-shale formations.

STRUCTURAL DEVELOPMENT OF LAS ANIMAS ARCH, LINCOLN, CHEYENNE, AND KIOWA COUNTIES, COLORADO[1]

JOHN C. MAHER[2]
Tulsa, Oklahoma

The Las Animas arch, also known as the Sierra Grande arch,[3] is a major structural feature trending northeastward across eastern Colorado and northeastern New Mexico. It is well defined in the exposed Cretaceous formations in Colorado[4] as shown in Figure 1.[5] Its expression in pre-Mesozoic rocks has been unknown for the most part, for data on the subsurface rocks are available for only a few widely separated wells. Because of the lack of detailed information, there are differences of opinion about the age and evolution of the arch.

Recent subsurface stratigraphic investigations, based on microscopic examination of cuttings from wells in western Kansas and southeastern Colorado by the Geological Survey, have revealed additional information regarding the structural development of the arch in Lincoln, Cheyenne, and Kiowa counties, Colorado. These data are included in a brief report and geologic cross section from Ness County, Kansas, to Lincoln County, Colorado, to be published at an early date by the State Geological Survey of Kansas in cooperation with the Federal Geological Survey. The present geologic note is abstracted from that report. The evolution of the Las Animas arch in this local area in eastern Colorado is shown in Figure 2 by a series of diagrammatic cross sections through the following four wells.

[1] Manuscript received, October 8, 1945. Published by permission of the director of the Geological Survey, United States Department of the Interior.

[2] Geologist, Geological Survey.

[3] J. L. Rich, "A Probable Buried Mountain Range of Early Permian Age East of the Present Rocky Mountains in New Mexico and Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (September–October, 1921), pp. 605–08.

[4] N. H. Darton, "Geology and Underground Waters of the Arkansas Valley in Eastern Colorado," *U. S. Geol. Survey Prof. Paper 52* (1906), Pl. 26.

[5] C. H. Dane and W. H. Pierce, "Geology and Oil and Gas Prospects in Part of Eastern Colorado," *U. S. Dept. Interior Press Release* (June 8, 1933).

No. 1 Gulf Oil Corp., No. 1 U.P.-Smith, C., SW., SE., Sec. 19, T. 15 S., R. 53 W.
No. 2 Gulf Oil Corp., No. 1 U.P.-Risser, NE., SW., SW., NE., Sec. 1, T. 17 S., R. 50 W.
No. 3 Morgan, Flynn, & Cobb, No. 1 Hostetter, C., NW., SE., Sec. 6, T. 20 S., R. 46 W.
No. 4 Stanolind Oil & Gas Co., No. 1 Snell, C., SE., SW., Sec. 7, T. 20 S., T. 41 W.

Figure 2-A represents the structural attitude of the Ordovician beds at the beginning of Mississippian deposition in the area. The eastward dip and eastward increase in thickness of the Viola and Arbuckle limestones was rather uniform across the area. The Viola limestone overlies successively older beds in the Ar-

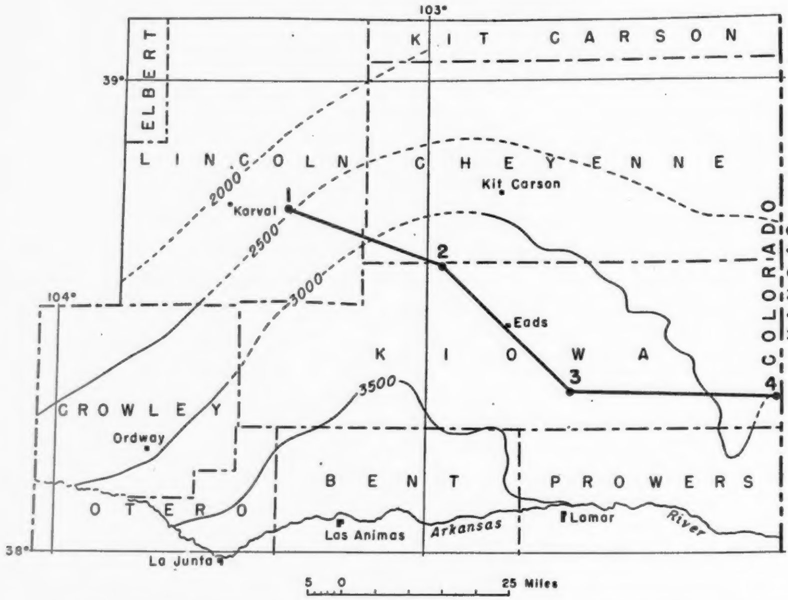


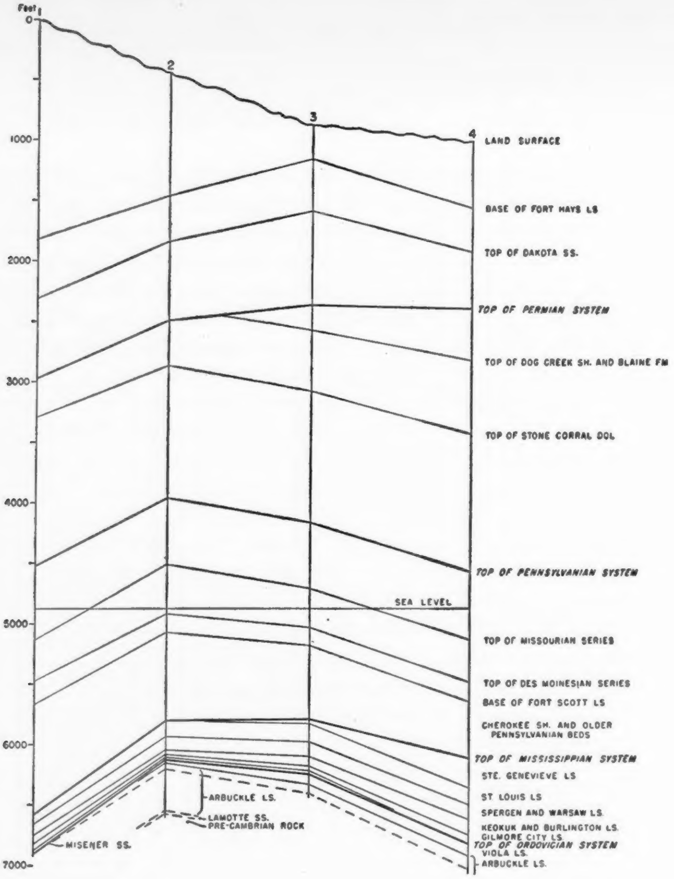
FIG. 1.—Map showing location of cross sections herein described and structure contours drawn on top of Dakota sandstone on Las Animas arch, after Dane and Pierce. Contour interval, 500 feet; figures on contours indicate feet above sea-level.

buckle westward and pinches out between wells 1 and 2. The westward thinning of these Ordovician beds may have been due in part to non-deposition and in part to regional erosion in post-Viola time.

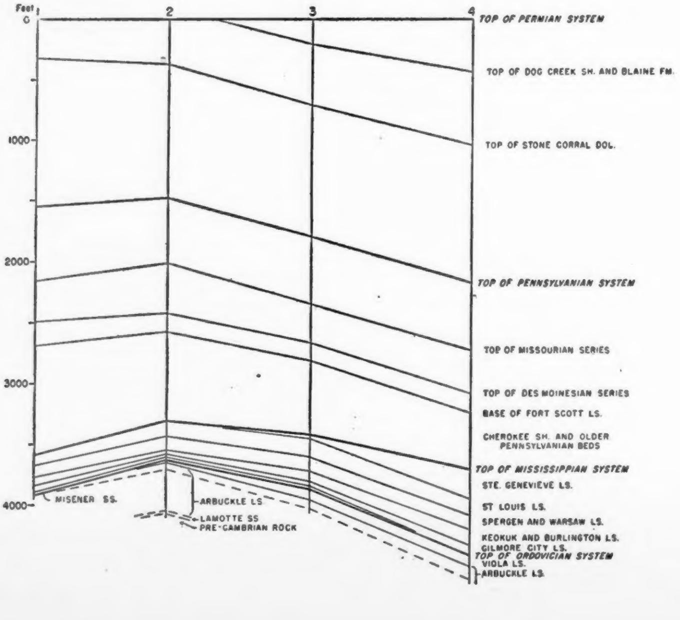
The facts shown in Figure 2-B suggest that the region of the arch subsided rather uniformly during Mississippian time, except for possible eastward tilting to form a basin or trough in which the thick Ste. Genevieve limestone was deposited. An alternative possibility is that this limestone was deposited uniformly over the arch and was partly removed by post-Mississippian erosion. The data from these four wells show that at the end of the period of post-Mississippian ero-

sion the Ordovician rocks formed a monocline dipping eastward at a low angle. Thereafter regional downwarping affected the western part of the area and thus created the earliest suggestion of anticlinal structure. Subsidence that formed a large basin including the western part of the area appears to have progressed during lower and middle Pennsylvanian time, for the thickness of a sequence of black shale and limestone of pre-Cherokee age and the thickness of the overlying beds of Des Moines age increases westward from well 4 to well 1. Figure 2-C shows that the arch was clearly defined by the end of Des Moines time, when the structural relief on the top of the Ordovician beds was about 200 feet.

The arch appears to have been accentuated by minor structural adjustments throughout late Pennsylvanian and most of Permian time. By the close of Stone Corral sedimentation (Fig. 2-D), the Ordovician beds were 300 to 350 feet higher structurally in well 2 near the crest of the arch than in wells 4 and 1 on the flanks. Prior to deposition of Mesozoic sediments over the Permian rocks (Fig. 2-E), the region had been tilted eastward and the younger Permian beds had been truncated; beds as old as the Dog Creek shale and the Blaine formation had been removed from the area including wells 1 and 2. Finally, Figure 2-F, which shows the present structural attitude of the Cretaceous and older rocks, indicates that considerable movement has occurred at times after the beginning of Mesozoic sedimentation, for the structural relief on the top of the Ordovician beds between the four wells is now about 750 feet.



F. At present time. (Logs aligned on sea-level datum)



E. At beginning of Mesozoic sedimentation in area. (Logs aligned on top of Permian rocks)

D. At end of Stone Corral sedimentation in late Permian time. (Logs aligned on top of Stone Corral dolomite)

C. At beginning of late Pennsylvanian sedimentation in area. (Logs aligned on top of Des Moinesian rocks)

B. At beginning of early Pennsylvanian sedimentation in area. (Logs aligned on top of Mississippian rocks)

A. At beginning of Mississippian sedimentation in area. (Logs aligned on top of Ordovician rocks)

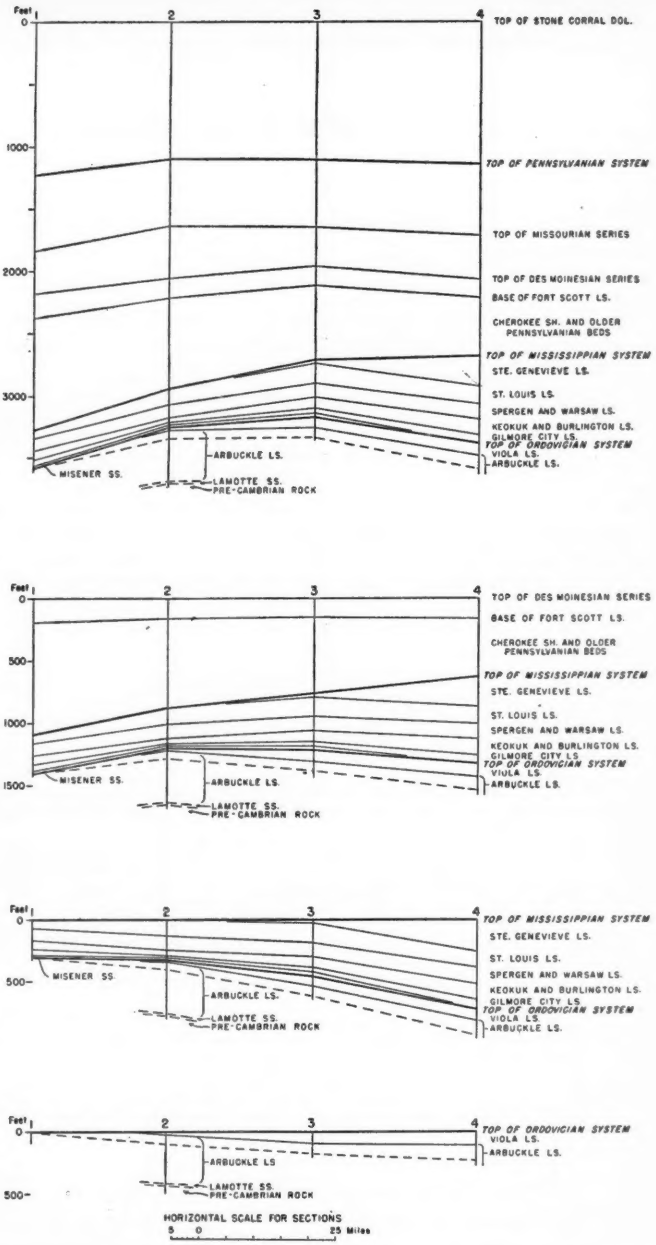


FIG. 2.—Diagrammatic sections, A to F, showing stages of structural development of Las Animas arch, between wells 1 and 4. Each erosional surface used as datum is assumed to have been horizontal. Geologic nomenclature follows usage of State Geological Survey of Kansas for most part. Sandstone at base of Mississippian system is termed "Misener" in accordance with local usage.

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RESEARCH NOTES

SELECTED REFERENCES ON RESEARCH[1]

S. W. LOWMAN[2]
Houston, Texas

A review of early literature on industrial and scientific research has revealed many articles that are pertinent to our present problems. Two of these have been mimeographed and are ready for distribution.

1. G. K. Gilbert, "The Special Processes of Research," *Amer. Jour. Sci.*, Vol. 133, No. 198 (June, 1887), pp. 452-73. (Pages 462-73 deal with the application of the graphic method and have not been copied.)
2. Arthur D. Little, "Industrial Research in America," *Science*, n.s., Vol. 38, No. 984 (November 17, 1913), pp. 643-56. (Parts omitted which deal with survey of research.)

Copies will be sent to all past and present members and consultants of the research committee and to all who have contributed to Research Notes. Copies will also be sent free of charge to other members of the Association who request them.[3] Other articles will be mimeographed during the year and will be sent as indicated above, and to anyone who wishes his name added to the mailing list.

Several other articles of special interest occur in the *Bulletin* and in other readily available publications.

D. C. Barton, "The State of Geologic Research in the Oil Industry," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 5 (May, 1937), pp. 665-74.

K. C. Heald, "Research and the American Association of Petroleum Geologists," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 9 (September, 1928), pp. 939-48.

R. R. Morse, "Outlook for Research in Exploration," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 8 (August, 1945), pp. 1203-07.

T. C. Chamberlin, "Studies for Students," *Jour. Geol.*, Vol. 5 (1897), pp. 837-48.

Ibid. (reprinted as), "The Method of Multiple Working Hypotheses," *Jour. Geol.*, Vol. 39 (1931), pp. 155-65.

Report of the Interdivisional Committee on Borderland Fields between Geology, Physics and Chemistry, T. S. Lovering, Chairman (1937). Division of Geology and Geography, National Research Council (2101 Constitution Avenue, Washington, D. C.). Price, $0.15.

Suggestions Concerning Desirable Lines of Research in the Fields of Geology and Geography (1936), edited by Edson S. Bastin, Carl O. Dunbar, and Robert S. Platt. Division of Geology and Geography, National Research Council (2101 Constitution Avenue, Washington, D. C.). Price, $0.15.

The Future of Industrial Research, Silver Anniversary Forum of Standard Oil Development Company. Privately printed (1945). (Available on request, Standard Oil Development Company, 30 Rockefeller Plaza, New York 20, N. Y.)

Science—The Endless Frontier. Report to the President on a Program for Postwar Scientific Research, by Vannevar Bush, Director of Office of Scientific Research and Development (July, 1945). (Superintendent of Public Documents, Washington, D. C.). Price, $0.30. This contains "Report of the Committee on Science and the Public Welfare," Isaiah Bowman, Chairman.

Research—A National Resource. II. Industrial Research (December, 1940). National Resources Planning Board. (Superintendent of Public Documents, Washington, D. C.). Price, $1.00.

[1] Manuscript received, October 21, 1945.

[2] Chairman, A.A.P.G. research committee. Shell Oil Company, Inc.

[3] Address requests for copies to Shepard W. Lowman, Box 2099, Houston, Texas.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

CANOL GEOLOGICAL INVESTIGATIONS IN THE MACKENZIE RIVER AREA, NORTHWEST TERRITORIES AND YUKON, BY G. S. HUME AND T. A. LINK

REVIEW BY J. V. HOWELL[1]
Tulsa, Oklahoma

"Canol Geological Investigations in the Mackenzie River Area, Northwest Territories and Yukon," by G. S. Hume and T. A. Link. *Canada Dept. of Mines and Resources, Geological Survey Paper 45-16.* Report of 87 pp. and 3 maps. Ottawa, Ontario (1945). Price, $0.25.

"This report is essentially a compilation of all geological surveys that have been made in the vicinity of Norman Wells, N.W.T. The data have been taken mainly from the recent Canol reports submitted to the Government of Canada by agreement with the United States Army and Imperial Oil, Ltd., and from earlier geological surveys carried out by Imperial Oil, Ltd., and by the Geological Survey."

The report, written largely by Hume, condenses and correlates the work of some 18 geologists of the Canol staff, as presented in 40 manuscript reports cited. The stratigraphic data are treated at length, and the structural data shown on many maps and by brief discussion of the structural features. Many folds suitable for testing are described.

Sixteen pages are devoted to the Norman Wells field, and to a detailed discussion of the drilling operations, accompanied by a map and cross sections.

Three maps (1 inch=8 miles) accompany this report and show the geology, so far as known, of the areas covered by the Canol explorations.

This report should be studied by any geologist interested in the Canol project or in Northwestern Canada. The authors have done an excellent job of condensation and the amount of data acquired under adverse conditions, by the Canol geologists, deserves unstinted praise, regardless of the economic merits of the entire operation.

RECENT PUBLICATIONS

ALABAMA

"Geologic Map of Tuscaloosa and Cottondale Quadrangles Showing Areal Geology and Structure of Upper Cretaceous Formations," by Louis C. Conant. *U. S. Geol. Survey Prelim. Map 37,* Oil and Gas Investig. Ser. (October, 1945). Sheet 27×52 inches. Scale, 1 inch equals 1 mile. Brief text. May be purchased from Director, Geological Survey, Washington 25, D. C. Price, $0.55.

BRAZIL

*"A bacia de Campos na geologia Litorânea do petróleo" (The Campos Basin [State of Rio de Janeiro] and the Littoral Geology with Reference to Petroleum), by Alberto Ribeiro Lamego. *Brazil Div. Geol. and Mineralogy Bull. 113* (Rio de Janeiro, 1944). 69 pp., 28 figs., 2 maps. In Portuguese.

[1] 1506 Philtower Building. Review received, October, 1945.

COLORADO

*"Calcareous Algae of the Upper Leadville Limestone [Mississippian] near Glenwood Springs, Colorado," by J. Harlan Johnson. *Bull. Geol. Soc. America*, Vol. 56, No. 9 (New York, September, 1945), pp. 829–48; 5 pls., 1 fig.

FRANCE

* "Transport et sédimentation dans l'estauire et a l'embouchure de la Gironde: caractères pétrographiques des formations fluviatiles, saumatres, littorales, et néritiques," by L. Glangeaud. *Bull. Géol. Soc. France*, Ser. 5, Tome 8, Nos. 7–8 (1938), pp. 599–630; 8 figs. Paris (June, 1939).

* "Les Marnes blanches aquitaniennes de Sanlucar de Barrameda (Prov. de Cadiz)" (The Aquitanian White Marls of Sanlucar, Barrameda), by A. Robaux. *Ibid.*, pp. 697–718; 1 pl. of diatoms.

GENERAL

**Oil and Petroleum Year Book, 1945*, compiled by Walter E. Skinner. 296 pp. Demy 8 vo, bound in red cloth. This is the thirty-sixth year of publication of the well known international reference book of the oil industry of the world; particulars about 541 companies. May be obtained from Walter E. Skinner, 20 Copthall Avenue, London, E. C. 2. Price, 13s. 6d. net, post free abroad.

*"Effect of Reservoir Fluid and Rock Characteristics on Production Histories of Gas-Drive Reservoirs," by M. Muskat and M. O. Taylor. *Petrol. Tech.*, Vol. 8, No. 5 (New York, September, 1945). 16 pp., 11 figs., 4 tables. *A.I.M.E. Tech. Pub. 1917.*

*"Some Practical Aspects of Radioactivity Well Logging," by Warren J. Jackson and John L. P. Campbell. *Ibid.* 27 pp., 19 figs. *A.I.M.E. Tech. Pub. 1923.*

*"Structural Interpretation of Micromagnetic and Other Data," by W. P. Jenny. *Oil Weekly*, Vol. 119, No. 6 (Houston, October 8, 1945), pp. 40–45, 12 figs.

*"Atoms, Energy, and Petroleum," by R. E. Fearon. *Independent Monthly*, Vol. 16, No. 6 (Tulsa, October, 1945), pp. 24–28; 3 figs.

MISSISSIPPI

*"Geology and Ground-Water Resources of the Coastal Area in Mississippi," by Glen Francis Brown, Velora Meek Foster, Robert Wynn Adams, Edwin William Reed, Harold Dement Padgett, Jr., in cooperation with the United States Geological Survey. *Mississippi Geol. Survey Bull. 60* (University, 1944). 232 pp., 23 figs., 14 pls., 18 tables.

MOROCCO

*"Observations nouvelles sur les rapports entre l'aire tectonique du Rif et celle du Moyen Atlas au Maroc Oriental" (New Observations on the Relation between the Tectonic Area of the Rif and That of the Middle Atlas in Eastern Morocco), by P. Russo. *Bull. Géol. Soc. France*, Ser. 5, Tome 8, Nos. 7–8 (1938), pp. 653–64; 1 map, 1 table showing lithologic character of the rocks by geologic age. Paris (June, 1939).

*"Contribution a l'étude du bord méridional des unités prérifaines entre Hajra el Baz et Moulay Yacoub (Maroc occidental)" (Study of Southern Border of Pre-Riffian Units between Hajra el Baz and Moulay Yacoub (Western Morocco), by Raymond Lévy. *Ibid.*, No. 9 (1938), pp. 771–94; 4 figs., 1 folded geologic map, 1 folded geologic section. Paris (July, 1939).

*"Les plissements post-nummulitiques dans l'Atlas saharien" (Post-Nummulitic Folds in the Saharan Atlas), by Robert Laffitte. *Ibid.*, Tome 9, Nos. 1, 2, 3 (1939), pp. 135–59; 8 figs., 1 pl. of 4 photographs. Paris (September, 1939).

NEBRASKA

*"Pre-Pennsylvanian Stratigraphy of Western Nebraska," by J. S. Dille. *Oil Weekly*, Vol. 119, No. 8 (Houston, October 22, 1945), pp. 45–47; paleogeological map.

NEW MEXICO

*"Stratigraphy and Oil-Producing Zones of the Pre-San Andres Formations of Southeastern New Mexico," by Robert E. King. *New Mexico Bur. Mines and Mineral Resources Bull. 23* (Socorro, 1945). 34 pp., 3 pls., 1 fig. Price, $0.50.

OHIO

"Map of the Berea Sand of Northern Ohio," by James F. Pepper, David F. Demarest, Wallace DeWitt, Jr., Richard D. Holt, and Charles W. Merrels 2d. *U. S. Geol. Survey Prelim. Map 39*, Oil and Gas Investig. Ser. (October, 1945). 2 sheets, each 40×44 inches. One is an isopach-contour map, showing oil pools. One contains several small maps, diagrams, sections, and text. May be purchased from Director, Geological Survey, Washington 25, D. C. Price, $0.65.

PACIFIC REGION

Fortress Islands of the Pacific, by William Herbert Hobbs. Published by J. W. Edwards. Contains 83 original maps and diagrams, 24 drawings from photographs taken by the author. Discusses geological origin, climate, resources, and people of the Pacific islands formerly mandated to Japan. May be ordered through *Science News Letter*, 1719 N Street, N.W., Washington 6, D. C. Price, $2.50.

RUSSIA

*"Correlations entre le Carbonifére de moyen la Russie et celui de l'Europe Occidentale" (Correlations between the Middle Carboniferous of Russia and Western Europe), by G. Deléphine. *Bull. Géol. Soc. France*, Ser. 5, Tome 8, Nos. 7–8 (1938), pp. 593–98; 1 correlation chart. Paris (June, 1939).

URUGUAY

*"Memoria Explicativa del Mapa Geológico del Departamento de Treinta y Tres" (Explanatory Text for the Geological Map of the Department of Treinta and Tres), by Nicolas Serra. *Inst. Geol. Uruguay Bol. 31* (Montevideo, December, 1944). 43 pp., 10 pls. Map in colors; scale, 1:250,000 (0.75 inch=kilometers); sheet, 32×20 inches.

UTAH

*"Scientific Explorations in Southern Utah," by Herbert E. Gregory. *Amer. Jour. Sci.*, Vol. 248, No. 10 (New Haven, Connecticut, October, 1945), pp. 527–549; 1 fig.

VENEZUELA

*"Fossil Fresh-water Mollusca from the State of Monagas, Venezuela," by Katherine Van Winkle Palmer. *Bulletins Amer. Paleontology*, Vol. 31, No. 118 (Paleontological Research Institution, Ithaca, New York, September 19, 1945). 34 pp., 3 pls.

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ANNUAL MEETING, CHICAGO, APRIL 2–4, 1946

The 31st annual meeting of the Association is scheduled to be held at the Stevens Hotel, Chicago, Illinois, on April 2, 3, and 4, 1946. This to be the usual joint annual meeting of the three exploration societies of the petroleum industry. The Society of Economic Paleontologists and Mineralogists will hold its 20th annual meeting, and the Society of Exploration Geophysicists will hold its 16th annual meeting. All sessions will be in the Stevens Hotel, which is the headquarters. This is a regular annual meeting for all the members, and it is hoped that sufficient transportation and hotel facilities will be available in April to accommodate members' wives and friends who may desire to attend. Further announcements will be made.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 11 (NOVEMBER, 1945), PP 1675-1682, 2 FIGS.

MEMORIAL

HAROLD BEACH GOODRICH
(1870–1945)

Harold Beach Goodrich was born at Hartford, Connecticut, on April 14, 1870, and passed away at his home in Tulsa, Oklahoma, April 25, 1945, culminating an active life in geology of 52 years. His geologic studies and field examinations took him to Alaska, Canada, South America, Mexico, and many parts of the United States.

He had suffered for several years with asthma which gradually reduced his resistance, and he was finally forced to give up the good fight. Surviving are the widow, Jessie King Weir, whom he married at Moncton, New Brunswick, Canada, on September 30, 1902, a brother, David, of Milwaukee, and a sister, Theo, of Boston. They had two daughters, Elizabeth, born August 7, 1907, and died August 9, 1907, and Freda Hollister, born August 14, 1908, and died of pneumonia at Ardmore, June 18, 1909. Even in this tragedy they never flinched but met friends and associates with that ever-ready smile and friendliness.

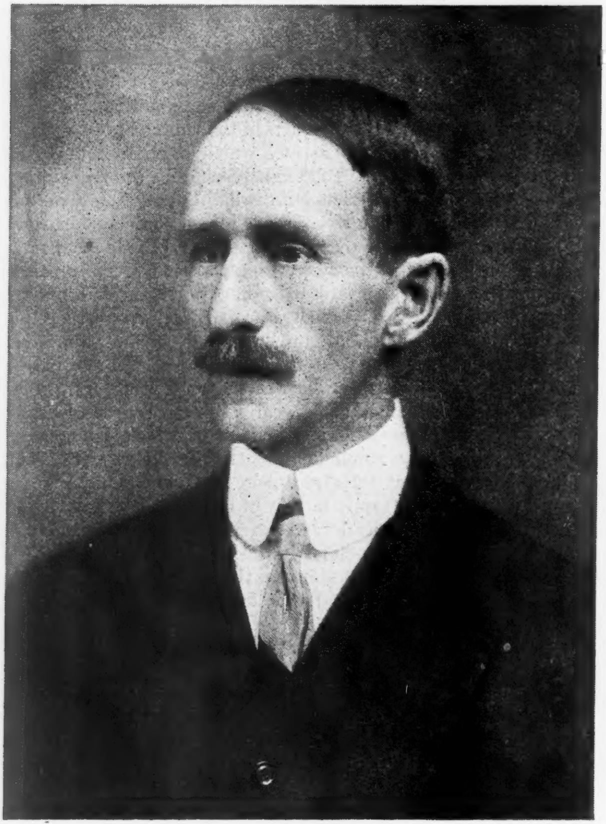
His father was Frederich Elizur Goodrich, a prominent journalist and publisher, who was associated with Edward Everett Hale in the *Commonwealth*, an aristocratic Boston paper, and wrote the editorials for the Boston *Post* which bore the stamp of his ability to express himself concisely and forcefully. He was known as the Dean of New England journalists, before he died at the age of 84 years. His mother was Elizabeth Williams (Parsons), a descendant of Roger Williams, founder of Rhode Island. Her father was Edward Parsons, a wealthy banker and industrialist of Hartford, Connecticut.

Harold's boyhood was spent in the atmosphere of a very happy home and a united family. His mother possessed the happy faculty of holding the family together and was gifted in other ways also. She was a leader in the activities of the Unitarian Church, composing lyrics and music for many church festivities.

His forbears and home environment stamped the man. He was always courteous, dependable, loyal, thorough, and modest and self-effacing to a fault. One of his best friends says, "Harold was a better man than most people in the oil country realized. While his great modesty was an admirable quality, that trait was a serious handicap in competition with many up-and-coming young geologists." He also stated that his geologic reports of fifty years ago show exacting scientific work, and were written in admirable language. Another says, "You can take from the dictionary all of the characteristics of a real man and then use them all. Harold was a wonderful companion. His was a happy home because they were admirably mated and Mrs. Goodrich contributed her share. She has what some women never acquire, charm spelled with a capital C. I have never known a more unselfish man, nor one who was more willing to help his fellow man when in need. He possessed no undesirable traits." From another, "His most striking characteristics were his meticulous attention to detail, his deep sense of responsibility, and the conscientious way in which he undertook anything. He took nothing for granted and when he made a statement, it was a certainty that he had checked all available data."

For the "Fiftieth Anniversary of the Harvard Class of 1892" Harold wrote, commenting on the progress of science in oil-finding and production, as well as in all branches of human endeavor, and concluded with, "The personal reaction is amazed admiration, with the realization that the seventy-year old individual, who often stumbles, may fall in the race."

He prepared for college at Boston Latin School, Boston, Massachusetts, and at Hartford Public High School, Hartford, Connecticut, graduating from the latter in 1888. He



Harold Beach Goodrich

lived with his grandparents while attending High School at Hartford. This was a great pleasure and satisfaction to him.

The colonial records of Connecticut show that a classical school was established in Hartford as early as 1638, which was supported partly by appropriations and partly by tuition fees. Two hundred and nine years later in 1847, this school became the Hartford Public High School, established as a free school for both male and female qualified children. Harold's mother was graduated from this school in 1858 and his father in 1860. Harold attended Harvard University from 1889 to 1892, receiving the A.B. degree. He attended the Harvard Graduate School from 1892 to 1893 and received the A.M. degree in geology out of course as of 1900. This degree was conferred for previous Graduate School work, and for field work in New Brunswick.

During summer vacations he was a reporter for his father's paper. He did not enjoy this assignment because it went against his nature, and especially when he had to report on someone's tragedy.

Except for his work with the United States Geological Survey and the Oklahoma Geological Survey, his whole professional career was as consulting geologist and engineer. His first and next to his last geologic assignment was with the United States Geological Survey. The first was in Alaska, and the southern Appalachians, and the last was in Oklahoma.

In 1893 a United States Geological Survey party composed of three young Harvard men, Spurr '92 leader, Schrader '93, and Goodrich '92, went into the Yukon wilderness, lived with the "sourdough" miners, and in the fall of 1896 brought out the news that a new gold region, the Klondike, had been discovered in British territory. This party was the first United States Geological Survey expedition into the interior of Alaska, and reported on the Yukon River gold fields at the time of the Klondike stampede. Let it be recorded again, however, that Spurr's scientific party had no share in the stampede, which emphasizes the integrity of these young scientists, for it is an unwritten law in the Survey that no information is given out prior to its publication. Following his return from Alaska, he wrote articles for magazines and lectured on Alaska.

In 1898 he was engaged by the Helena Mining Company as surveyor, assayer, engineer, and assistant superintendent in a silver mine at Cosihuirachic, Mexico. This assignment came through his father's half-brother, Robert Rhea Goodrich, a mining engineer.

Harold was a real pioneer in the application of geology to oil-finding and its production. From 1899 to the end he practiced as petroleum geologist and engineer and in this profession he has the longest record of continuous service of anyone in the United States.

His first consulting work in petroleum geology was for the New Brunswick (Canada) Petroleum Company in 1899 under the supervision of Professor N. S. Shaler, Dean of the Scientific School of Harvard. The object was a geologic study to determine the oil and gas possibilities in the Province of New Brunswick, Canada. The report was favorable, drilling was done with Goodrich as superintendent, and oil was discovered at Memramcook.

There is no reasonable doubt that Goodrich's early work helped to establish the petroleum and natural gas industry in New Brunswick. The Stony Creek gas field, for which he made a favorable report, is an example. Several years after Goodrich finished his work in the Province, a successor company discovered gas in commercial quantities in this field. From then until to-day, this field has supplied gas to various cities in the area. Active development is still going on and the productive limits of the field are not yet defined.

His meticulous attention to detail and the thoroughness with which he worked are illustrated by the fact that a system of very detailed tabulation for recording well logs used by him in this early work is still the standard practice in current development in the area. There is evidence that Goodrich made a very careful study of well samples and cores from diamond core holes drilled during his sojourn there or prior to his arrival. The Canada Geological Survey has published a number of these logs by Goodrich in the ap-

pendix to the "Report on the Coal Prospects of New Brunswick, by Henry S. Poole, 1903," page 19 MM.

He was the first geologist to engage in commercial petroleum work in what is now Oklahoma. He was attracted to Indian Territory by reported seepages, and moved from Houston, Texas, to Ardmore, Oklahoma, in 1903.

During the period from 1901 to 1910 he was an independent consultant for various clients including seven years for the Atchison, Topeka, and Santa Fe Railway Company.

He was employed by the Doheny interests in 1902 to study and report on the oil and gas possibilities in the Tampico district of Mexico. It is believed that his report was the first commercial geological report on this district.

During his employment by the Santa Fe Railway Company he was petroleum geologist and manager of the fuel and oil department. His studies and operations included California, Florida, Utah, Texas, Kansas, and Oklahoma. His efforts were rewarded by the development of substantial oil production at Saratoga, Texas, and he located the first Santa Fe (now Coline Oil Company) well which discovered the prolific Wheeler field in Carter County, Oklahoma. It is reported that the discovery well in this field was the first dry gas well in the state of Oklahoma, and was the beginning of the development that was to make Oklahoma one of the great oil-producing states in the nation. A commercial supply of gas was developed and a $6\frac{1}{4}$-inch pipeline to Ardmore was completed and gas was turned into the line December 12, 1907.

Another example of his thoroughness and geological judgment was his recommendation to his client, the Santa Fe Railway Company, that it buy heavily in the area of the now great Healdton field in Carter County, Oklahoma. This recommendation was made in advance of its discovery by the Dundee Oil Company in August, 1913. The field has produced well in excess of 200,000,000 barrels of oil, and after 32 years, is currently producing more than 6,000 barrels per day.

His next important assignment was with the Madera-Mamore Railway Company (British interests), La Paz, Bolivia, South America, in 1910 and 1911. He was sent to investigate the oil possibilities in the upper Amazon River. It is of interest to quote his own words about that journey, printed in the "Fiftieth Anniversary Report of Harvard College, Class of 1892," pages 107–08.

> The high Andes were crossed in snow and ice; rapids were shot, and broad rivers traveled by raft and canoe; tropical jungles traversed on foot or on mule-back; the calls of parrots and monkeys; the flies and mosquitos, and oh! the jungle fever! These are the memories of thirty years ago.

The hardships suffered on this trip undermined his health and may have contributed to some of his illness in later life.

After returning from Bolivia he spent the next twenty-four years as consultant for various clients, which required intermittent assignments in Mexico and many of the states. He was employed as specialist in 1913 and 1914 by the United States Bureau of Mines to make a report on conservation for prevention of waste in the Cushing field, Oklahoma, and the Midway field, California. These reports were not published. He was also employed by the Dundee Petroleum Company as supervisor of drilling crews during the development of the Healdton field, Oklahoma, in 1915. He moved to Tulsa, Oklahoma, in 1915 and remained there in consulting practice during the balance of his life.

In 1918 and 1919 he was employed as a specialist in petroleum geology and engineering by the United States Treasury Department, Federal Income Tax Bureau, to assist in the compilation of the first "Manual for the Oil and Gas Industry."

During 1934 he was employed by the United States Geological Survey under the supervision of N. W. Bass, to collect and study the subsurface geology of Osage County, Oklahoma. From September, 1938, to August, 1939, he was again employed on the same project

to assist in the preparation of maps, well-log data, and proof-reading for *Bulletin 900.* Herewith are Bass' comments on Goodrich's part in the Osage County project.

He contributed valuable service for the entire project, but particularly for the northeastern corner of the county and the Burbank oil field. He is senior author of *Bulletin 900-F* entitled "Subsurface geology and oil and gas resources of Osage County, Oklahoma, Part 6, T. 28 N., Rs. 10 and 11 E., and T. 29 N., Rs. 9 to 11 E.," and is the junior author of *Bulletin 900-I*, which is on Twps. 23 and 24 N., R. 7 E., including the Naval Reserve field, and is junior author of *Bulletin 900-J* which includes the Burbank and South Burbank fields. Mr. Goodrich is mainly responsible for the structure contour map of the Burbank field which is included in *Bulletin 900-J*.

He was employed on an Oklahoma mineral survey from November, 1935, to December, 1936. Herewith are remarks by R. H. Dott, State geologist.

With reference to H. B. Goodrich's connection with the Oklahoma Geological Survey, he was employed on our State mineral survey, a W.P.A. project, as County supervisor of Tulsa County, and later as field geologist on a project in which he and the late C. T. Kirk collaborated in mapping and sampling the Oologah limestone in Tulsa County. This latter was a real contribution, and will be incorporated by Mr. Oakes in his forthcoming report on Tulsa County.

Goodrich was again employed by the United States Geological Survey from November, 1943, to May, 1944, under the supervision of Parker D. Trask to compile information on the nature, distribution, and geology of the asphalt and tar-sand deposits of Oklahoma. This work was a part of the Survey's war-time investigations of our oil and gas resources. He was thorough in this, as in all his professional career, and he exhausted the many sources of information, including published material, personal conferences, and field note books of the Oklahoma Geological Survey. Because he was a pioneer in Oklahoma geology and thus knew personally the geology and geologists, the file prepared by him is a valuable source of information on asphalt and tar sands in Oklahoma.

Following the completion of the foregoing assignment, he was employed by the Oklahoma Geological Survey to digest and index all the old-field notebooks that had accumulated since territorial days down to 1931 when the Survey closed. The purpose of this work was to ascertain what of interest and value might be buried in these old notebooks. The study resulted in uncovering much valuable information that can be put to some useful purpose.

He never held a public office, though he took United States Civil Service examinations and received rating on the list of eligibles without subsequent appointment, for the following positions, (1) Geologist, U.S.G.S., 1900; (2) Appraisal Petroleum Engineer, Federal Income Tax Bureau, 1922 or 1923; (3) Postmaster, Tulsa, 1932.

With exception of being a signing author on parts of the Yukon River gold-field report, and magazine articles and lectures on the Alaskan subject, his writing has been on the petroleum industry and its applied geology, most of which, however, was never published.

He was a member of the American Institute of Mining and Metallurgical Engineers from 1912 to 1931 and served as chairman of the Mid-Continent section in 1922. He became a member of the American Association of Petroleum Geologists in 1918 and was elected an honorary member in 1929 in recognition of his "long experience and honorable activity in the profession of petroleum geology and particularly his faithful and valuable service in the Association." He is to date the only Tulsa member to receive this honor. He was a member of the Tulsa Geological Society since its organization in 1920.

He was a frequent contributor to trade and technical publications.

In languages he read and spoke fluently Spanish, read and wrote French and read German.

He was a Unitarian.

He lived a long, useful, and scientifically productive life. His family, his friends, and his colleagues have lost a loving husband and companion, a true and loyal friend, and an outstanding scientist.

The following sources of information in the preparation of this memorial are gratefully acknowledged: Harvard College Class of 1892, Report XV, Fiftieth Anniversary, 1942; Catalogue of the Hartford Public High School, 1932; W. R. Hamilton, C. L. Severy, R. H. Dott, N. W. Bass, Hugh D. Miser, J. P. D. Hull, J. V. Howell, and Mrs. H. B. Goodrich.

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   (i) Part 9, "Townships 23 and 24 North, Range 7 East," by N. W. Bass, W. R. Dillard, L. E. Kennedy, and H. B. Goodrich. 1941, pp. I-III, 303-19, Pl. 9.
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FRANK R. CLARK

TULSA, OKLAHOMA
October, 1945

EDGAR WAYNE GALLIHER
(1907-1945)

The many friends of Dr. Edgar Wayne Galliher in Southern California as well as throughout the country were greatly saddened to learn of his accidental death on April 29, 1945. It is difficult to become reconciled to the loss of such a brilliant and affable young man just at the time when he was ready to enter upon the most productive years of his life. "Doc," or Wayne, as he was known to his numerous friends, will long be remembered for his cheerful and friendly manner as well as for his ability as a scientist and economic geologist.

Dr. Galliher has contributed greatly to the geological sciences by his original work in the field of sedimentation. His publications summarizing exhaustive studies on the formation and deposition of glauconite are classics, and for the first time proved the origin of this peculiar mineral. His observations on the mode of deposition of glauconite are of great value to the stratigraphic geologist in his interpretation of the physical conditions at the time rocks containing glauconite were deposited. His deep thinking, so well exhibited in his scientific studies, was carried over into the field of petroleum geology, where his creative ideas were of help to him in his position of chief geologist of the California division of the Barnsdall Oil Company.

Dr. Galliher was born, September 10, 1907, in McPherson, Kansas. His childhood was spent on the Crow Indian Reservation at the Crow Agency, Montana, and later in Bozeman, Montana. He attended high school in Palo Alto and entered Stanford University in 1925, where he graduated with a Bachelor of Arts degree in 1929. In the years 1929 to

Gladser Studio, Los Angeles

EDGAR WAYNE GALLIHER

1931 he obtained his Master of Arts degree in geology, and received the degree of Doctor of Philosophy in geology a year later in 1932. During the summer of 1929, he was engaged in a geologic reconnaissance of British Columbia for the Richfield Oil Company. In the summer of 1930 he was an instructor for the Stanford University field geology class, and from 1932 to 1935 he was a consulting geologist. In 1935, Dr. Galliher became associated with the Barnsdall Oil Company and in 1937 became chief geologist of the California division of that company.

Scientific societies to which he belonged in addition to the American Association of Petroleum Geologists are Sigma Xi, the American Institute of Mining and Metallurgical Engineers, and the Geological Society of America.

Dr. Galliher is survived by his wife, Alice Sohlinger Galliher, and two daughters Susan and Sally.

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ROBERT T. WHITE

LOS ANGELES, CALIFORNIA
August 18, 1945

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VOL. 29, NO. 11 (NOVEMBER, 1945) PP. 1683-1692

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The following officers were elected for the 1945–1946 season of the Houston Geological Society: president, OLIN G. BELL, Humble Oil and Refining Company; vice-president, SHAPLEIGH G. GRAY, Independent; treasurer, M. M. SHEETS, Stanolind Oil and Gas Company; secretary, HARRY KILIAN, Independent, 1235 Commerce Building. Members of the advisory committee are: A. F. CHILDERS, JR., Gulf Oil Corporation; H. L. GEIS, Barnsdall Oil Company; L. H. MORRIS, of J. S. Abecrombie.

New officers of the Appalachian Geological Society are: president, R. B. ANDERSON, Columbian Carbon Company, Charleston, West Virginia; vice-president, C. E. STOUT, Parkersburg; vice-president, RALPH N. THOMAS, Inland Gas Corporation, Ashland, Kentucky; secretary-treasurer, W. B. MAXWELL, Box 1273, Charleston; editor, H. J. SIMMONS, JR., Charleston.

CARROLL H. WEGEMANN, who has been with the Petroleum Administration for War at Denver, Colorado, is retiring from government service. He plans to do some consulting work. His home is 722 East Seventh Avenue, Denver.

FRANK S. WESTMORELAND is employed by the Atlantic Refining Company at Houston, Texas.

WILLIAM P. WILLIAMS has left the Stanolind Oil and Gas Company, Amarillo, Texas, to be with the geological division of the State Department of Conservation, Trenton, New Jersey.

DEANE J. WOLFF is in the employ of the Kerlyn Oil Company, Oklahoma City. He was previously with the Magnolia Petroleum Company at Dallas.

President MONROE G. CHENEY has discussed "Association Affairs" at the meetings of many local geological societies this year. He appeared recently on programs of the Tulsa Geological Society and the Oklahoma City Geological Society.

Major ELMER W. ELLSWORTH, consulting geologist of Centralia, Illinois, has been assigned to General MacArthur's headquarters. Last March he completed 2½ years as chief of the Information Collecting and Records Section of the AAF Arctic, Desert and Tropic Information Center. His address is APO 19705-D2, c/o P.M., San Francisco, California.

HOMER C. MOORE has resigned his position as manager of the geology and geophysics departments of the Mid-Continent Petroleum Corporation, Tulsa. He plans to open a consulting office.

ROBERT F. WALTERS, of the Gulf Oil Corporation, talked before the Tulsa Geological Society, October 1, on "Pre-Cambrian Hills in the Kraft-Prusa District, Northeastern Barton County, Central Kansas."

CHARLES C. O'BOYLE, formerly with the Anchor Exploration Company, Golden, Colorado, is with the Geotechnical Corporation, Cambridge, Massachusetts, as research geophysicist.

GORDON R. MCNUTT has been released from active military service and is assistant professor of geology at the University of Texas, Austin.

CARLETON D. SPEED, JR., formerly of Houston, is superintendent of exploration and chief geologist of the Plymouth Oil Company, Sinton, Texas.

RALPH HENRY WILPOLT is associate professor of geology at the New Mexico School of Mines, Socorro, New Mexico.

FRANK E. BROWN, formerly with the Shell Oil Company, Inc., is now in the employ of the Republic Exploration Company, Tulsa.

H. C. FOUNTAIN, formerly with the Magnolia Petroleum Company, is connected with the Bureau of Economic Geology, Austin, Texas.

The annual meeting of the Geological Society of America will be held at the Hotel William Penn, Pittsburgh, Pennsylvania, December 27–29, 1945, as announced by H. R. ALDRICH, secretary, 419 West 117th Street, New York 27, N. Y.

FRANK REEVES is in consulting geological work. His address is Kensington, Maryland. Reeves was recently in the Office of Petroleum Administration for War at Washington, D. C. For many years he was with the United States Geological Survey.

FORBES S. ROBERTSON is in the geological department of the Carter Oil Company at Lander, Wyoming.

NICHOLAS A. ROSE, of the United States Geological Survey, has been transferred from Houston, Texas, to El Dorado, Arkansas, to take charge of a cooperative investigation of the ground-water resources of Arkansas to be carried on by the Survey and the Arkansas Bureau of University Research. Rose and W. F. GUYTON are the authors of a recent report, "Quantitative Studies of Some Artesian Aquifers in Texas," published in *Economic Geology* (May, 1945).

Captain JACK B. RYAN is on terminal leave from the Army, attending the University of Oklahoma at Norman.

Captain MAXWELL R. SARTAIN is in the Intelligence Section, Orlando Army Air Base, Orlando, Florida.

LINCOLN E. WARREN has left the position of assistant geologist with the Bureau of Economic Geology of the University of Texas to take the position of geologist with the Gulf Oil Corporation, Fort Worth.

The home address of Lieutenant Colonel LEAVITT CORNING, JR., is 410 Eldon Road, San Antonio, Texas.

WILLIAM B. HEROY, JR., formerly with The Texas Company at Midland, has joined the Geotechnical Corporation at Dallas, Texas.

FRANK C. KALLINA has left the Continental Oil Company to join the Standard Oil Company of Texas, Milam Building, San Antonio, Texas.

NOYES B. LIVINGSTON has completed a 2-year contract as chief geologist for the Yacimientos Petroliferos Fiscales Bolivianos, and after a 2-months trip through the principal cities of Argentina, Uruguay, and eastern Brazil, he is now an independent geologist at 1608 Congress Avenue, Austin, Texas.

KENNETH P. MCLAUGHLIN, who has been working for the Stanolind Oil and Gas Company at San Antonio, Texas, may now be addressed in care of the School of Geology, Louisiana State University, Baton Rouge, Louisiana.

William W. Mallory, recently in the employ of the Phillips Petroleum Company, is now in the department of geology, University of Columbia, New York City.

Walter Randall, formerly with the Stanolind Oil and Gas Company, is with the Texas Petroleum Company at Bogota, Colombia.

Robert B. Totten is district geologist for the Sun Oil Company in Arkansas and North Louisiana. His present address is Delhi, Louisiana.

John Bruce Scrafford is engaged in consulting geology, 2000 Driscoll Building, Corpus Christi, Texas.

Lyman Toulmin, Jr., formerly with the Geological Survey of Alabama, is at Birmingham-Southern College, Birmingham, Alabama.

Carl T. Anderson has left the Republic Natural Gas Company, Dallas, to become an independent geologist in the Staley Building, Wichita Falls, Texas.

Lieutenant Colonel H. H. Arnold, Jr., who has been on the Staff Faculty of the Engineer School, Fort Belvoir, Virginia, may be addressed at 749 Liberty Street, Clarion, Pennsylvania.

Hubert M. Bristol, formerly with the Ohio Oil Company, is connected with the Luttrell Oil Properties, Effingham, Illinois.

Don L. Carroll, recently on the editorial staff of the *Oil Weekly*, Houston and New York, is chief of the section of Geological Information and Reports, United States Geological Survey, Geologic Branch, Washington 25, D. C.

James F. Gibbs has left the Standard Oil Company of Texas, to engage in consulting geology at 505 City National Bank Building, Wichita Falls, Texas.

Joseph John Uri has recently been discharged from the Navy after more than 3 years of service, 2 years of which were spent in Guadalcanal, Bougainville, and New Zealand. He is with the British-American Oil Producing Company, Ricou-Brewster Building, Shreveport, Louisiana.

The Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, listened to Charles B. Hunt, United States Geological Survey, present a paper on "Geology Applied to Military Intelligence, on October 19. Other speakers planned for future meetings at Denver are: Chester R. Longwell, of Yale University, "Stratigraphic and Structural Problems of the Basin Ranges of Southern Nevada and West Arizona"; Bailey Willis, of Stanford University, "Terrestrial Dynamics"; Harold W. Scott, of the University of Illinois, "Upper Paleozoic History of Northern Rocky Mountains and Adjacent Plains"; Parke A. Dickey, of the Quaker State Oil Refining Company, Bradford, Pennsylvania, "Secondary-Recovery Methods"; T. S. Oakwood, of Pennsylvania State College, "Chemical Origin of Oil."

Major Bernard Esunas, of Byrd-Frost, Inc., Dallas, Texas, may be addressed: H.A.A.F., Harvard, Nebraska.

Walter L. Youngquist may be addressed at the Geology Department, University of Iowa, Iowa City, Iowa.

Charles R. Clark, recently with the Lake Oil Company, is now with the Kerlyn Oil Company, First National Bank Building, Oklahoma City, Oklahoma.

JACK B. COLLINS, of the United States Geological Survey, has been transferred from Nashville, Tennessee, to Tulsa, Oklahoma, for work in the field section.

The Petroleum Division of the American Institute of Mining and Metallurgical Engineers held its fall meeting in sections: October 8, Tulsa; October 10, Houston; October 12–13, Fort Worth; October 19, Los Angeles.

The 75th anniversary celebration of the A.I.M.E. is scheduled for September 16–18, 1946, at the Waldorf-Astoria Hotel, New York City.

E. D. LYNTON, geologist for the California Research Corporation, San Francisco, spoke at the meeting of the Pacific Section of the A.A.P.G. in Los Angeles, September 14. He told of the work done by the United States Government in rehabilitating the industries, mines, oil fields, and railroads of French North Africa for the American Army of Occupation during 1943 and 1944. Lynton was chief of the procurement and development division of the North African Economic Board.

JOHN TAYLOR SINCLAIR, JR., is no longer affiliated with the Tide Water Associated Oil Company. He is petroleum engineer for the Pantepec Oil Company of Venezuela, Apartado 888, Caracas.

WALTER C. WASSEN has left the United States Geological Survey to join the Standard Oil Company of Texas. His address is Box 862, El Paso, Texas.

Lieutenant LOUIS C. ROARK of Tulsa, Oklahoma, was discharged from military duty in September, after 57 months in the service. He was a navigator on a B-24 in the South Pacific area, having been 14 months overseas, and having gone on 43 missions. At the time of his discharge he was adjutant at the Graduate School of Navigation at Ellington Field, Texas. Roark will take graduate work in geology at Leland Stanford University.

RAY C. LEWIS, formerly district geologist for the Stanolind Oil and Gas Company, has been appointed chief geologist of the Houston Oil Company of Texas, Houston.

W. B. HEROY, director of the Division of Foreign Production, Petroleum Administration for War, was on the program of the 16th annual meeting of the Independent Petroleum Association of America in Tulsa, Oklahoma, October 14–17. His subject was "World Oil Supply."

F. M. VAN TUYL, professor of geological engineering and head of the department at the Colorado School of Mines, is spending October and November in South America in professional work, having been retained by a group of industrialists to act in an advisory capacity in planning a long-term exploratory program for the development of mineral resources.

FRANK M. ANDERSON, consulting geologist and paleontologist and pioneer in the field of California stratigraphy and oil exploration, died at his home, 58 Hillcrest, Berkeley, California, on September 24, 1945, at the age of 82 years. Anderson was also a member of the California Academy of Sciences in the capacity of honorary curator of paleontology at the time of his death.

BRUCE LAWRENCE CLARK, professor of paleontology at the University of California and member of the California Academy of Sciences, died in September at Berkeley, California, at the age of 65 years.

ROBERT W. BURGER, district geologist for The Texas Company in the San Joaquin and Sacramento valleys, California, died on September 25 at the Good Samaritan Hospital in Los Angeles, at the age of 39 years.

Lieutenant Commander CHARLES DEBLIEUX, on military leave of absence from Stanolind Oil and Gas Company, has returned to civilian status.

Major JULIUS B. GARRETT, Stanolind Oil and Gas Company, has been awarded the bronze star for meritorious achievement in the Mediterranean theater of operations.

At the annual meeting of the Paleontological Research Institution, held at its headquarters, October 6, 1945, in Ithaca, New York, the following officers were elected for the ensuing year: president, RALPH A. LIDDLE, Fort Worth, Texas; vice-president, AXEL A. OLSSON, Gloversville, New York; secretary, REBECCA S. HARRIS, Ithaca, New York; treasurer, GILBERT D. HARRIS, Ithaca; assistant treasurer, KATHERINE V. W. PALMER, Ithaca. Owing to uncertainties of obtaining suitable materials and labor for the construction of a new building at the present time, this work has been temporarily postponed. Satisfactory progress is being made in the publication of the *Bulletins of American Paleontology* and *Paleontographica Americana*, and in work on the Carpenter types.

WILLIS M. DECKER has returned to the Cities Service Oil Company as geologist at Oklahoma City, Oklahoma. He joined the Navy in February, 1942, and left the service with the rank of Lieutenant in October, 1945. He was a naval aviator.

Lieutenant Commander SHERMAN A. WENGERD, of the Shell Oil Company, Inc., has returned from service in Alaska in the United States Navy Department, Naval Petroleum Reserve No. 4. He was engaged in aerial photographic interpretation.

H. J. GRUY is now employed by DeGolyer and MacNaughton, Dallas, Texas.

KENNETH H. CRANDALL has been elected president and J. W. HOOVER vice-president of The California Company, New Orleans, Louisiana.

A. C. WATERS has returned to the department of geology at Stanford University, after several years with the United States Geological Survey at Washington, D. C.

W. H. TWENHOFEL, professor of geology at the University of Wisconsin, is spending the winter at Orlando, Florida. His temporary address is Route 3, Box 460, Orlando. Editorial correspondence about the *Journal of Sedimentary Petrology* should continue to go to him at the University of Wisconsin, Madison, Wisconsin.

JOHN F. DODGE, head of the division of petroleum engineering at the University of Southern California, Los Angeles, is vice-president and manager of the Pantepec Oil Company of Venezuela.

WILLIAM L. HORNER, Barnsdall Oil Company, spoke on "Water Injection to Increase Recovery and Rates, Midway Field, Arkansas," at the meeting of the Shreveport Geological Society, Shreveport, Louisiana, October 22.

J. BRIAN EBY, consulting geologist and geophysicist of Houston, Texas, is traveling in Germany, reporting the condition of oil fields and development for the *Oil Weekly*.

DISTINGUISHED LECTURE TOUR

CHARLES B. HUNT, United States Geological Survey, Washington, D. C., head of the Military Unit of the Survey, opened the 1945–46 season during October. His subject was "Geology Applied to Military Intelligence." His address was based on the vital work which the Military Geology Unit did during World War II in preparing terrane intelligence studies for the Military Intelligence Division in the office of the Chief of Engineers. He addressed the following societies.

October	8	Pittsburgh Geological Society at Pittsburgh
	9	Appalachian Geological Society at Charleston, West Virginia
	10	Ohio State University at Columbus
	11	Michigan Geological Society at Lansing
	12	Joint meeting of Illinois Geological Society and Indiana-Kentucky Geological Society at Olney, Illinois
	15	Alberta Geological Society at Calgary
	18	Wyoming Geological Association at Casper
	19	Rocky Mountain Association of Petroleum Geologists at Denver, Colorado
	22	Kansas Geological Society at Wichita
	23	Bartlesville Geological Society at Bartlesville (Luncheon)
	23	Tulsa Geological Society at Tulsa
	24	Oklahoma City Geological Society at Oklahoma City
	25	Fort Worth Geological Society at Fort Worth
	26	North Texas Geological Society at Wichita Falls
	29	Dallas Petroleum Geologists at Dallas
	30	East Texas Geological Society at Tyler
	31	Houston Geological Society at Houston
November	1	Corpus Christi Geological Society at Corpus Christi
	2	South Louisiana Geological Society at Lake Charles
	5	Shreveport Geological Society at Shreveport
	6	Mississippi Geological Society at Jackson
	8	Southeastern Geological Society at Tallahassee

FRED H. MOORE, *chairman*

MT. VERNON, ILLINOIS
October 16, 1945

MISSISSIPPI GEOLOGICAL SOCIETY FIELD TRIP, DECEMBER 7–8

The Mississippi Geological Society will sponsor a field trip covering the Eutaw and Tuscaloosa sections in western Alabama, December 7 and 8, in cooperation with the United States Geological Survey and the Alabama Geological Survey.

Participants will assemble in Eutaw, Alabama, at 10 A.M., Friday, December 7, and, following an inspection of the Eutaw formation type locality and lunch at Eutaw, will proceed across the Eutaw and Tuscaloosa sections to Tuscaloosa where a night stop will be made.

The second day, Saturday, December 8, the formations of the Tuscaloosa group will be examined in the general vicinity of Tuscaloosa. The trip will end in Tuscaloosa.

Reservations for the night of December 7, in Tuscaloosa, may be made at the following: McLester Hotel; Campus Courts; Sunset Rest Courts; Moonwinx Courts.

It is suggested that confirmation of reservations be requested, since accommodations are limited at each hotel and court.

Walter B. Jones, Alabama State geologist, University, Alabama, will also arrange for additional accommodations in Tuscaloosa and requests for reservations may be directed to the office of the State geologist.

PACIFIC SECTION ANNUAL MEETING, NOVEMBER 8–9

The 22d annual meeting of the Pacific Section of the Association at Los Angeles, California, was the occasion also for the annual meeting of the Pacific Section of the Society of Economic Paleontologists and Mineralogists, and the meeting of the Pacific Coast District of the Society of Exploration Geophysicists. The program follows.

S. E. G., November 7, Gold Room, Ambassador Hotel.

Presiding in Forenoon—J. J. JAKOSKY and C. H. DRESBACH, Los Angeles.

1. Opening Remarks, by J. J. JAKOSKY, vice-president of S. E. G.

2. The Attenuation Constant of Earth Materials, II.—W. T. BORN, Geophysical Research Corporation, Tulsa, Oklahoma.
3. Repeated P-Waves in Seismic Exploration of Water-Covered Areas—ROY L. LAY, The Texas Company, Houston, Texas.
4. Application of Continuous Profiling for Refraction Shooting—A. J. BARTHELMES, Seismograph Service Corporation, Tulsa, Oklahoma.
5. Airplane-Nose Interference with Seismic Prospecting—J. M. KENDALL, Naval Ordnance Laboratory, Washington, D. C.
6. Refraction Waves Reflected at a Fault Zone—W. B. ROBINSON, Gulf Research and Development Company, Pittsburgh, Pennsylvania.
   Luncheon in French Room.
   Presiding in Afternoon—PHILIP P. GABY, Fresno, and H. R. THORNBURGH, Los Angeles.
7. Address, by HENRY C. CORTES, president of S. E. G., Magnolia Petroleum Company, Dallas, Texas.
8. Some Political and Economic Aspects of a Foreign Exploration Program—A. C. RUBEL, Union Oil Company of California, Los Angeles, California.
9. Recent Developments in Geochemical Prospecting for Petroleum—LEO HORVITZ, Horvitz Research Laboratories, Houston, Texas.
10. The Petroleum Supply to the United States Forces in Europe—HOWARD C. PYLE, vice-president, Bank of America, former Lieutenant Colonel in U. S. Army, Deputy Chief of Oil Supply Branch in Europe.
11. Seismograph Evidence on the Depth of the Salt in Southeast Texas—H. WAYNE HOLYMAN, Gulf Research and Development Company, Pittsburgh, Pennsylvania.
12. Gravity Results over Kettleman Hills and Lost Hills, California—LEWIS H. BOYD, Brown Geophysical Company, Tallahassee, Florida.

A. A. P. G., November 8, Amassador Theater.
   Presiding in Forenoon—E. ROBERT ATWILL, Los Angeles.
1. Results of California Exploration during the War Period—FRANK S. PARKER, Signal Oil and Gas Company, Los Angeles, California.
2. Buena Vista Hills (27-B Pool)—EVAN BURTNER, Standard Oil Company of California, Taft, California.
3. Nomination of Officers, Pacific Section (GLENN H. BOWES, presiding).
4. Stratigraphic and Structural Problems of Southern Nevada and Western Arizona—CHESTER R. LONGWELL, A.A.P.G. distinguished lecturer, Yale University, New Haven, Connecticut.
   Luncheon in Embassy Room. Toastmaster—GLENN H. BOWES, president, Pacific Section. Remarks by A. A. P. G. president M. G. CHENEY, Coleman, Texas.
   Presiding in Afternoon—JAMES C. KIMBLE, Bakersfield.
5. Geology of Tierra del Fuego, South America—JOSEPH S. HOLLISTER, consulting geologist, Gaviota, California.
6. Stratigraphic Section East of Bogota, Colombia, South America—THOMAS CLEMENTS, University of Southern California, Los Angeles, California.
7. The First Oligocene Mammalian Fauna from Northern South America—R. A. STIRTON, University of California, Berkeley.
8. Recent Investigations by the Geological Survey of Alaska's Petroleum Possibilities—JOHN C. REED, United States Geological Survey, Washington, D. C.
9. Late Paleozoic and Early Mesozoic Strata of the Uinta Mountains, Utah—HORACE D. THOMAS, University of Wyoming, Laramie, Wyoming, and MAX I. KRUEGER, Union Oil Company of California, Laramie, Wyoming.

S. E. P. M., November 8, Clark Hotel.
   Dinner, Business Meeting, Election of Officers.

Presiding—STANLEY S. SIEGFUS, president, Pacific Section.
"Paleocene" Beds of San Joaquin Valley, California—GLENN C. FERGUSON, consulting paleontologist, Bakersfield, California.

A. A. A. P., November 9, Ambassador Theater.
Presiding in Forenoon—ROLLIN ECKIS, Bakersfield.

10. Notes on the Geology of the Deep Coles Levee Well, Kern County, California—N. L. TALIAFERRO, University of California, Berkeley, California and W. F. BARBAT, Standard Oil Company of California, Los Angeles.
11. Notes on Rocky Mountain Thrust Faults—EDWARD C. H. LAMMERS, Standard Oil Company of California, Los Angeles, California.
12. Business Meeting—GLENN H. BOWLES, presiding.
13. Terrestrial Dynamics—BAILEY WILLIS, A. A. P. G. distinguished lecturer, Stanford University, California.
Presiding in Afternoon—HOMER J. STEINY, Los Angeles.
14. Landslides—Ventura Avenue Oil Field—CLAUDE E. LEACH, Tide Water Associated Oil Company, Ventura, California, and HENRY H. NEEL, Tide Water Associated Oil Company, Ventura, California.
15. Use of Geology in the Southwestern Pacific Area—WILLIAM C. PUTNAM, University of California at Los Angeles, Los Angeles, California.
16. The Most Powerful Man in the World—MORTIMER KLINE, attorney, Los Angeles, California.
Dinner Dance, Embassy Room, A.A.P.G., S.E.P.M., S.E.G.

FOR AVAILABLE GEOLOGISTS

The Association invites oil companies and other employers who desire the services of geologists to list their needs with

A.A.P.G. HEADQUARTERS
BOX 979, TULSA 1, OKLAHOMA

The executive committee desires to remind the members and associates that the Association offers the facilities of the Headquarters office to those seeking employment. The committee desires in particular to offer its services to those who have served in the Armed Forces and are now released and seeking employment. File a complete record of your education and experience with J. P. D. Hull, business manager, Box 979, Tulsa, Oklahoma. He will bring your qualifications to the attention of those who have filed their needs with his office. A member of the national service committee will be available for counsel.

Lieutenant Colonel LEAVITT CORNING, JR., is separated from active service with the Air Forces and will resume consulting practice in San Antonio, Texas. Corning has the

Bronze Star, Legion of Merit, and nine battle stars from his 34 months overseas service in the Mediterranean and European war theaters.

Major ATLEE G. MANTHOS is separated from active service with the Air Forces and will resume his practice at San Antonio. Manthos served 14 months overseas with the 8th Air Force in England as Combat Pilot, flying 37 missions escorting bombers over Germany and France.

Lieutenant Colonel EDGAR W. OWEN recently received the Legion of Merit for outstanding work overseas with the 5th Air Force and later with the Far Eastern Air Command. He is now on staff duty with the latter Command in Tokyo.

Colonel BYRON RIFE recently received the Legion of Merit for his work in Army Ordnance. At present he has charge of the Kankeekee and Elwood Ordnance Works, Joliet, Illinois.

H. E. SUMMERFORD, stratigrapher and subsurface geologist for the Shell Oil Company at Oklahoma City, has resigned to become district geologist for the Rocky Mountain district for the Kerlyn Oil Company. Office and resident will be in Casper, Wyoming.

CARLETON D. SPEED, JR., moved from Houston, August 1, to Sinton, Texas, where he became superintendent of exploration and chief geologist for the Plymouth Oil Company. Although the Plymouth operates throughout the United States, it main office is located in southwest Texas near fields largely owned by the company. Speed served 2 years in the Petroleum Administration for War in Washington, 6 months of the time with the Special Assistants' staff of Ralph K. Davies, deputy petroleum administrator for war, and 1½ years as chief of exploration of the Production Division of the Petroleum Administration for War.

JAMES O. LEWIS, consulting petroleum engineer of Houston, Texas, has been awarded the Anthony Lucas Medal of the American Institute of Mining and Metallurgical Engineers in recognition of "distinguished achievement in improving the technique and practice in finding and producing petroleum."

The Society of Economic Geologists will hold its annual meeting at the Hotel William Penn, Pittsburgh, Pennsylvania, December 28 and 29.

ERNEST O. SCHILLHAHN, geologist with the Manufacturers Light and Heat Company, Pittsburgh, Pennsylvania, died on August 3, at the age 38 years.

WILLIAM W. PORTER II, consulting geologist, 244 South Gramercy Place, Los Angeles, California, has returned from an assignment in Venezuela and a trip through Colombia.

J. J. RUSSELL, JR., has resigned his position with the Sinclair Prairie Oil Company and has opened an office for independent geological work in the Allison-Duncan Building, Wichita Falls, Texas.

Lieutenant Colonel HUBERT G. SCHENCK is now chief of the Natural Resources Section, General Headquarters of the Supreme Commander for the Allied Powers, in Tokyo.

ANDREW KIRK MCGILL is chief geologist of Peruvian operations for the Socony-Vacuum Oil Company, Inc. He is located at 810 Avenida Wilson, Lima, Peru.

W. B. PERRY is with the Kingwood Oil Company, Jackson, Mississippi.

MARVIN LEE, consulting geologist, has moved his office from Wichita, Kansas, to 511 Pickwick Building, 903 McGee Street, Kansas City, Missouri.

J. B. SELOVER has been released from active naval duty. He had the rank of Lieutenant Commander. His present connection is the Fisher Oil Company, Evansville, Indiana.

J. H. POTEET, formerly district geologist for The Texas Company at Evansville, Indiana, is now geologist for the Frontier Fuel Oil Company at Evansville, Indiana.

R. H. DANA has left the United Geophysical Company to join the staff of the Southern Geophysical Company, Fort Worth, Texas.

Lieutenant LANGDON C. TENNIS is Counter Intelligence Officer for the 4th Air Force, March Field, Riverside, California. He plans to remain in the Army Air Corps for the present.

The New Orleans Geological Society of New Orleans, Louisiana, will have the following officials for the coming year: president, B. E. BREMER, The Texas Company, Box 252; vice-president, R. R. COPELAND, JR., The California Company, 1818 Canal Building; secretary-treasurer, R. W. BYBEE, Humble Oil and Refining Company, 1405 Canal Building. The Society meets the first Monday of every month, October to May inclusive, 7-30 P.M., St. Charles Hotel. Special meetings are held by announcement. Visiting geologists are cordially invited.

NATIONAL RESEARCH FELLOWSHIPS IN NATURAL SCIENCES

(Mathematics, Astronomy, Physics, Chemistry, Geology, Paleontology, Physical Geography, Zoology, Botany, Agriculture, Forestry, Anthropology, and Psychology)

These Fellowships, administered by the National Research Fellowship Board in the Natural Sciences of the National Research Council, are intended to promote fundamental research in the natural sciences, primarily in educational and research institutions of the United States. They are awarded as a rule to persons under thirty-five years of age who are citizens of the United States or Canada, and who have met all of the requirements for the Doctor's degree not later than the close of the calendar year in which the application is filed (whether or not the degree has been conferred), or who have by the time of application presented evidence of experience and attainment in research equivalent to that of persons who have qualified for the Doctor's degree.

The Board will consider granting a limited number of Participating Fellowships which are designed to provide approximately a half-time research Fellowship in combination with a half-time instructorship.

The basic stipend is $2,000 per annum, with an additional allowance for travel. Larger stipends may be granted to Fellows with dependents. Appointments are for one year. Reappointments may be made in exceptional cases only. The closing date for the receipt of applications for 1946–1947 will be December 31, 1945. Awards will be made about March 15, 1946.

The Board requires that each applicant for a Fellowship shall be nominated by a sponsor who is well acquainted with him both personally and professionally.

For further information concerning these Fellowships, address: National Research Fellowship Board in the Natural Sciences, National Research Council, 2101 Constitution Avenue, Washington 25, D. C.

PROFESSIONAL DIRECTORY

TEXAS

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS

DENVER, COLORADO

President - - - - - - - - - J. J. Zorichak
Petroleum Administration for War
First National Bank Building

1st Vice-President - - - - John Vanderwilt
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2nd Vice-President - - - - Max L. Krueger
Union Oil Company of California

Secretary-Treasurer - - - - Robert McMillan
Frontier Refining Company
First National Bank Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - Lee C. Lamar
Carter Oil Company, Box 568, Mattoon

Vice-President - - - - - - - - Jack Hirsch
The Texas Company, Mattoon

Secretary-Treasurer - - - - - Gene Gaddess
Pure Oil Company, Olney

Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY

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President - - - - - - - - Stanley G. Elder
Sun Oil Company

Vice-President - - - - - Hillard W. Bodkin
The Superior Oil Company

Secretary-Treasurer - - - - - Jess H. Hengst
Barnsdall Oil Company

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY

WICHITA, KANSAS

President - - - - - - - - - Virgil B. Cole
Gulf Oil Corporation

Vice-President - - - - - - - Laurence C. Hay
Consulting Geologist, 402 Union National Bank Building

Secretary-Treasurer - - - Edward A. Huffman
J. M. Huber Corporation, 407 First National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY

NEW ORLEANS, LOUISIANA

President - - - - - - - - - B. E. Bremer
The Texas Company, P.O. Box 252

Vice-President and Program Chm. - - - - - - - - - - - - - R. R. Copeland, Jr.
The California Company, 1818 Canal Bldg.

Secretary-Treasurer - - - - - R. W. Bybee
Humble Oil and Refining Co., 1405 Canal Bldg.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY

SHREVEPORT, LOUISIANA

President - - - - - - - - - T. H. Philpott

Vice-President - - - - - - Van D. Robinson
Atlantic Refining Company

Secretary-Treasurer - - - - - W. E. Wallace
Sohio Petroleum Corporation, Atlas Building

Meets the first Monday of every month, September to May, inclusive, 7:30 P.M., Criminal Court Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY

LAKE CHARLES, LOUISIANA

President - - - - - - - - Max Bornhauser
Continental Oil Co., Box 569, Lafayette

Vice-President - - - - - A. Lyndon Morrow
Magnolia Petroleum Co., Box 872

Secretary - - - - - - - Bruce M. Choate
Atlantic Refg. Co., Box 895

Treasurer - - - - - - - - P. F. Haberstick

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - Kenneth K. Landes
University of Michigan, Ann Arbor

Vice-President - - - - - - - - T. J. Weaver
Michigan Consolidated Gas Co., Grand Rapids

Secretary-Treasurer - - - Manley Osgood, Jr.
Cities Service Oil Co., Box 149, Mt. Pleasant

Business Manager - - - Harry J. Hardenberg
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

TEXAS

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - Thomas B. Romine
Sinclair Prairie Oil Company, 901 Fair Building

Vice-President - - - - - William J. Nolte
Stanolind Oil and Gas Company, Box 1410

Secretary-Treasurer - - - Spencer R. Normand
Independent Exploration Company
2210 Ft. Worth Natl. Bank Bldg.

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - - Olin G. Bell
Humble Oil and Refining Company

Vice-President - - - - - Shapleigh G. Gray
Independent

Secretary - - - - - - - - - - Harry Kilian
Independent
1235 Commerce Building

Treasurer - - - - - - - - - M. M. Sheets
Stanolind Oil and Gas Company

Regular meeting held the first and third Thursdays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - William Lloyd Haseltine
Magnolia Petroleum Co., Box 239

Vice-President - - - - Charles R. Canfield
Stanolind Oil and Gas Company
909 Hamilton Building

Secretary-Treasurer - - - - John R. Davis
Superior Oil Company, 807 Hamilton Building

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

President - - - - - - - - Harvey Whitaker
1409 Milam Building

Vice-President - - - - - - George H. Coates
638 Milam Building

Secretary-Treasurer - - - - Marion J. Moore
Transwestern Oil Company, 1600 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - F. H. McGuigan
Lion Oil Refining Company

Vice-President - - - - - Leo R. Newfarmer
Shell Oil Company, Inc.

Secretary-Treasurer - - - - - Alan B. Leeper
Honolulu Oil Corporation

Meetings will be announced.

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P. O. Box 2605

President - - - - - - - - R. B. Anderson
Columbian Carbon Company

Vice-President - - - - - - - - C. E. Stout
Parkersburg

Vice-President - - - - - Ralph N. Thomas
Inland Gas Corp., Ashland, Kentucky

Secretary-Treasurer - - - - W. B. Maxwell
United Fuel Gas Company, Box 1273

Editor - - - - - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June July, and August, at 6:30 P.M., Kanawha Hotel.

WYOMING

WYOMING GEOLOGICAL ASSOCIATION
CASPER, WYOMING
P. O. Box 545

President - - - - - - - - William H. Curry
Atlantic Refining Company

1st Vice-President - - - - - Robert L. Sielaff
Sinclair-Wyoming Oil Company

2nd Vice-President (Programs) - P. W. Rinehart
Shell Oil Company, Inc.

Secretary-Treasurer - - - David T. Hoenshell
General Petroleum Corporation

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special Meetings by announcement.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - - Henry C. Cortes
Magnolia Petroleum Co., Dallas, Texas

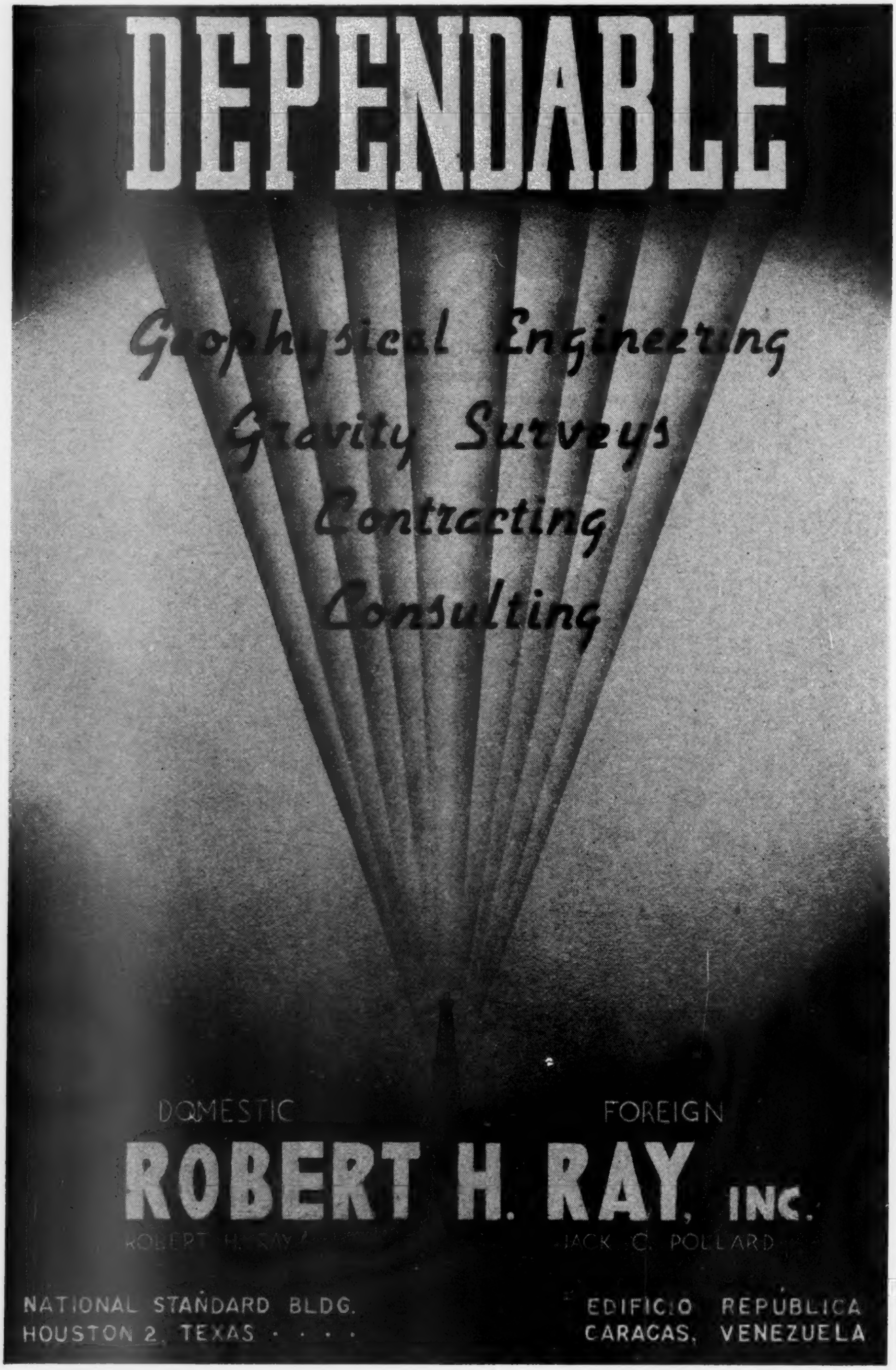
Vice-President - - - - - - - - J. J. Jakosky
University of Southern California, Los Angeles

Editor - - - - - - - - - L. L. Nettleton
Gulf Research Laboratory, Pittsburgh, Pennsylvania

Secretary-Treasurer - - - - Cecil H. Green
Geophysical Service, Inc., 1311 Republic Bank Building, Dallas, Texas

Past-President - - - - William M. Rust, Jr.
Humble Oil & Refining Company, Houston

Business Manager - - - - - - - - E. Stiles
Hamilton, Texas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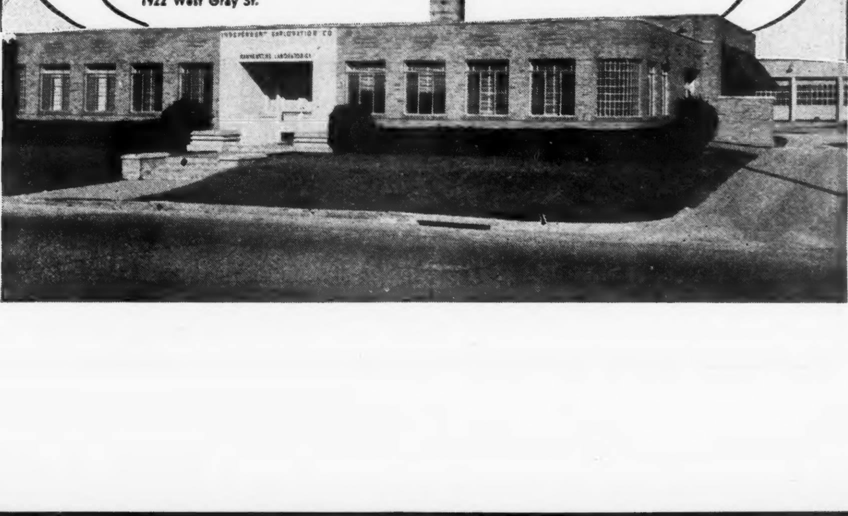

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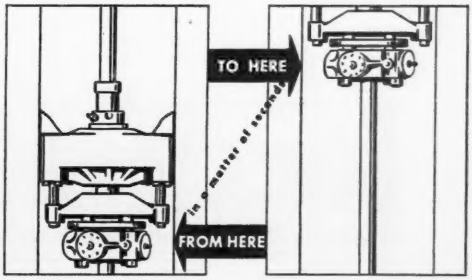

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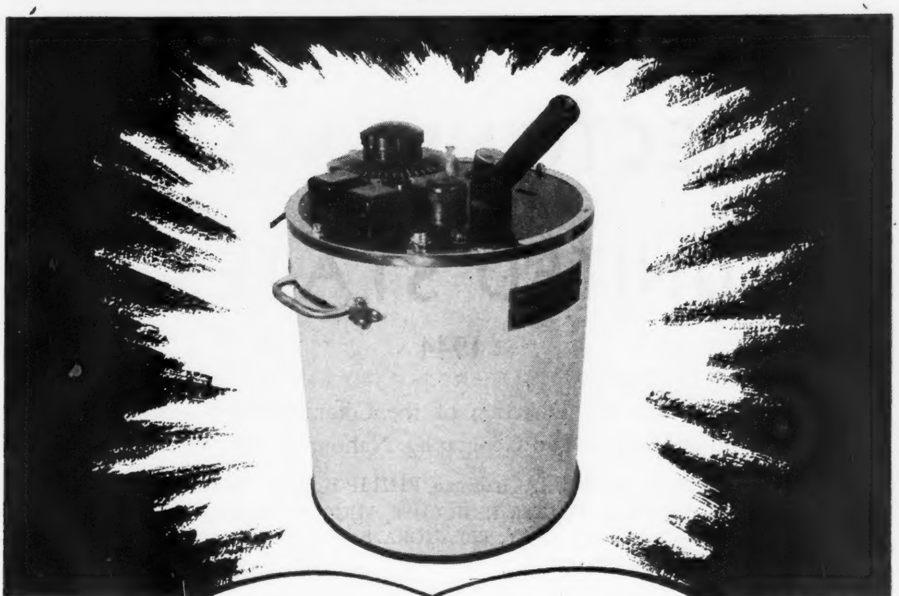


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